PWS-600
Data Logger

User's Manual

14-10600
03/17/2014

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1 Regulatory Information 6
1.1 FCC Statement 6
1.2 Battery Statement 6
2 Warranty and Assistance 7
3 Overview 8
4 Specifications 9
5 Installation 13
5.1 Environmental Considerations 13
5.2 Mounting the Device 13
5.3 Connector Pin-Out 14
5.4 Terminal Block Accessory 15
5.5 Power Requirements 16
5.6 Charging Requirements 16
5.7 Status Indicators 17
5.8 Communication 18
5.8.1 RS485 Signals 18
5.8.2 RS232 Signals 18
6 Getting Started 19
6.1 Device Configuration 19
6.2 Network Communication Settings 19
6.3 Site Identification 19
6.4 Configure the Sensor Networks 20
6.5 Configure the Data Log 20
7 Register Map 21
7.1 Device Configuration Registers 21
7.1.1 Register Map Version 21
7.1.2 Device Id 21
7.1.3 Serial Number 21
7.1.4 Firmware Version 21
7.1.5 Boot Code Version 21
7.1.6 Hardware Version 22
7.1.7 Site Id 22
7.1.8 Site Name 22
7.1.9 Site Information 22
7.1.10 Device Address 22
7.1.11 Low Voltage Warning Threshold 22
7.2 Device Command Register 23
7.3 Device Status Registers 25
7.3.1 Device Status 25
7.3.2 Ambient Temperature 26
7.3.3 Input Voltage 26
7.3.4 Charge Voltage 26
7.3.5 Date and Time 26
7.4 Communication Configuration Registers 27
7.4.1 Communication Settings 27
7.4.2 Message Timeout 28

7.4.3 Sleep Timeout 28
7.4.4 Message Counters 28
7.5 Sensor Networks 29
7.5.1 RS485 Smart Sensor Network 29
7.5.2 SDI-12 Smart Sensor Network 35
7.5.3 Analog Sensor Network 37
7.5.4 Discrete Sensor Network 38
7.6 Data Log Configuration Registers 39
7.6.1 Log Enable 40
7.6.2 Log Pause 40
7.6.3 Next Scheduled Record 41
7.6.4 Log Interval 41
7.6.5 Log Offset 41
7.6.6 Number of Sensor Commands 41
7.6.7 Sensor Command Groups 42
7.6.8 MODBUS Command Group Format 42
7.6.9 SDI-12 Command Group Format 44
7.6.10 Analog Command Group Format 46
7.6.11 Discrete Command Group Format 49
7.6.12 Last Sensor Readings 51
7.7 Switched Power Outputs 52
7.7.1 Switched Output Status 52
7.7.2 Switched Power Output Configuration 53
7.8 Discrete Outputs 55
7.8.1 Discrete Output Status 55
7.8.2 Discrete Output Configuration 55
7.9 Data Log Recording Registers 57
7.9.1 Encryption Key 57
7.9.2 Recording Data 57
7.9.3 Recording Speed 58
7.10 Data Log Retrieval Registers 59
7.10.1 Data Log Size 59
7.10.2 Data Log Used 59
7.10.3 Lowest and Highest Record Numbers 59
7.10.4 Download Record Count 60
7.10.5 Record Number 60
7.10.6 Record Size 60
7.10.7 Record Data 60
7.10.8 Data Decryption 61
7.10.9 Data Retrieval Procedure 61
7.10.10 Data Log Download Command 61
7.10.11 Last Data Log Record 63
7.11 Sensor Network Pass-Through Registers 64
7.11.1 Sensor Network 64
7.11.2 MODBUS Protocol Pass-Through 64
7.11.3 SDI-12 Protocol Pass-Through 64

7.12 Password Security Registers 66
7.12.1 Security Password 66
7.12.2 Login Password 66
7.13 Diagnostic Registers 67
7.13.1 Configuration Flash Writes 67
7.13.2 Last Reset Type 67
7.13.3 Fault Information 68
7.13.4 High and Low Temperatures 68
7.13.5 Data Log Chip Id 68
7.13.6 Data Log Erasure Count 68
8 MODBUS Protocol 69
8.1 RTU Transmission Mode 69
8.1.1 RTU Character Format 69
8.1.2 RTU Message Format 70
8.2 ASCII Transmission Mode 70
8.2.1 ASCII Character Format 70
8.2.2 ASCII Message Format 71
8.3 MODBUS IP 72
8.4 Device Addressing 72
8.5 Data Types 72
8.5.1 USHORT: Unsigned Short 72
8.5.2 SHORT: Signed Short 73
8.5.3 ULONG: Unsigned Long 73
8.5.4 LONG: Signed Long 73
8.5.5 FLOAT: Floating Point 73
8.5.6 STRING: Character String 74
8.5.7 TIME: Date and Time 74
8.6 Function Codes 75
8.6.1 Report Slave Id 75
8.6.2 Read Registers 75
8.6.3 Write Multiple Registers 77
8.6.4 Write Single Register 78
8.6.5 Exception Response 79

1 Regulatory Information

The PWS-600 has been tested and approved to be compliant to the following regulatory standards.

- EN61326-1: 2006, for immunity in industrial locations (CE)
- EN55011: 2009, Class A, Group 1, for emissions (CE)
- CISPR 11, Ed. 5.0, 2009-05, Class A, Group 1, for emissions
- CFR Title 47: FCC Part 15, Class A, for emissions

Any changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

1.1 FCC Statement

This device has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This device generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with this manual, may cause harmful interference to radio communications. Operation of this device in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

1.2 Battery Statement

This device contains a poly-carbonmonoflouride lithium coin cell battery to preserve the real-time clock when power is not applied. The Department of Transportation requires that the outside of each package that contains primary lithium batteries, regardless of the size or number of batteries, be labeled with the following statement: "PRIMARY LITHIUM BATTERIES – FORBIDDEN FOR TRANSPORT ABOARD PASSENGER AIRCRAFT". The labeling requirement covers shipping via highway, rail, vessel or cargo-only aircraft and covers all shipments into or out of the United States. The label must be in contrasting color and the letters must be 12 mm (0.5 in) in height for packages weighing more than 30 Kg and 6 mm (0.25 in) in height for packages weighing less than 30 Kg.

The lithium battery does not contain enough lithium to qualify as a reactive hazardous waste. The battery is safe for disposal in the normal municipal waste stream.

2 Warranty and Assistance

The PWS-600 is warranted by Prairie Wind Systems, LLC to be free from defects in materials and workmanship under normal use and service for twelve (12) months from the date of shipment unless specified otherwise. Prairie Wind Systems' obligation under this warranty is limited to repairing or replacing, at Prairie Wind Systems' option, defective products. The customer shall assume all costs of removing, reinstalling, and shipping defective products to Prairie Wind Systems. Prairie Wind Systems will return such products by surface carrier prepaid. This warranty shall not apply to any product which has been subjected to modification, misuse, neglect, accidents of nature, or shipping damage. This warranty is in lieu of all other warranties, expressed or implied, including warranties of merchantability or fitness for a particular purpose. Prairie Wind Systems is not liable for special, indirect, incidental, or consequential damages.

Products may not be returned without prior authorization. To obtain a Returned Materials Authorization (RMA) number, contact Prairie Winds Systems at the phone number below. Please write the RMA number clearly on the outside of the shipping container. Prairie Wind Systems' shipping address is:

Prairie Wind Systems, LLC
RMA #_____
7784 Big Sky Court
Windsor, CO 80550

support@prairiewindsystems.com
Phone: 970.460.6066
Fax: 970.692.2434

3 Overview

The PWS-600 is a MODBUS slave device that periodically polls and logs data from a wide variety of analog, discrete, and smart sensors. The current readings from the sensors are available to the MODBUS master device via a block of MODBUS holding registers.

Readings are polled and logged at the programmed rate and are automatically time-stamped and check-summed. When the memory is full, recording automatically wraps around to record the newest data over the oldest data. All data are stored in non-volatile flash memory which does not require power for data retention. Standard write and read register commands are used to extract logged data from the device.

In addition to the data logging feature, the PWS-600 extends the capabilities of a system with these additional features.

- Data can be recorded and retrieved securely using the Advanced Encryption Standard with a user-defined key.
- The PWS-600 includes an accurate, temperature-compensated, real-time clock. Every data record is date and time stamped. Polling and logging are synchronized to the real-time clock, making it easy to align data collection across multiple systems.
- The PWS-600 includes a built-in solar charge controller compatible with standard 12 volt sealed lead-acid batteries, reducing a system's overall cost and complexity.
- The device's ambient temperature and input voltages are logged with every data record for enhanced data tracking and system troubleshooting, particularly in battery operated systems. The user can track battery and recharging performance in standalone and solar charged systems.

The Prairie View Software that comes with the device provides a convenient means to configure the device and manage its data log.

4 Specifications

Case	
Description	ABS plastic with integral mounting flanges
Dimensions	6.62"L x 3.30"W x 1.30"H (16.8 x 8.4 x 3.3 cm) including flanges and connector
Weight	6.1 oz (173.6 g)
Ratings	IP 66 and NEMA 4X
Connector	44-pin D-sub socket
Environmental	
Operating Temperature	-40 to 70 °C (-40 to 158 °F)
Operating Humidity	5 to 95 %RH non-condensing
Storage Temperature	-40 to 80 °C (-40 to 176 °F)
Battery Input	
Input Voltage	8 to 32 Vdc
Transient Protection	250 Watts Peak
Sleep Current	< 500 µA typical at 13.5 Vdc, RS485 and RS232 networks inactive
Idle Current	500 µA typical at 13.5 Vdc, RS485 and RS232 networks inactive
Active Current	30 mA typical at 13.5 Vdc, not including sensor load currents
Battery Charge Controller	
Input Voltage	15 to 32 Vdc
Transient Protection	250 Watts Peak
Battery Rating	12 Vdc, 2.3 to 7.0 Ahr, Sealed Lead-Acid
Peak Charge Current	1 A
Charging Temperature	-15 to 45 °C (5 to 115 °F) charging disabled outside of this range
MODBUS RS485 Transceiver	
Unit Load	1/8
Termination	None
Common Mode Range	+/- 7 Vdc
Transient Protection	250 Watts Peak
Protocol	Half-Duplex, MODBUS over Serial Line
Transmission Modes	RTU, ASCII, IP
Addressing	1 to 247 plus broadcast
Baud Rates	1200, 2400, 4800, 9600, 19200, 38400, 57600
Data Bits	7, 8
Parity	Odd, Even, None
Stop Bits	1, 2

MODBUS RS232 Transceiver	
Type	9-pin DTE (data terminal equipment)
Port Power	Switched, +5V, 275 mA
Input Voltage Swing	+/- 25 Vdc absolute maximum
Output Voltage Swing	+/- 5 Vdc minimum
ESD Protection	+/- 15 kV
Protocol	Half-Duplex, MODBUS over Serial Line
Transmission Modes	RTU, ASCII, IP
Addressing	1 to 247 plus broadcast
Baud Rates	1200, 2400, 4800, 9600, 19200, 38400, 57600
Data Bits	7, 8
Parity	Odd, Even, None
Stop Bits	1, 2
Smart Sensor RS485 Port	
Unit Load	1/8
Termination	4.75K ohm polarity terminations
Common Mode Range	+/- 7 Vdc
Transient Protection	250 Watts Peak
Protocol	Half-Duplex, MODBUS over Serial Line or SDI-12
Transmission Modes	RTU, ASCII
Addressing	1 to 247 plus broadcast
Baud Rates	1200, 2400, 4800, 9600, 19200, 38400, 57600
Data Bits	7, 8
Parity	Odd, Even, None
Stop Bits	1, 2
Smart Sensor SDI-12 Port	
SDI Version	1.3
Data Line	Bidirectional, tri-state, 5V logic
Transient Protection	250 Watts Peak
Analog Voltage Sensor Inputs	
Inputs	6 single-ended or 3 differential
Single-ended Ranges	0 to 5000, 0 to 2000, 0 to 1000, 0 to 500 mVdc
Differential Ranges	±2000, ±1000, ±500, ±250, ±125, ±60, ±30 mVdc
Resolution	0.002 %FS
Accuracy	±0.05% of reading ±0.01 %FS over operating temperature range
Voltage Excitation	4.096 Vdc ±0.05%, 30 mA maximum
Resistive Excitation	3900 ohms ±0.15%, connected to the voltage excitation

Current Loop Terminations	
Terminations	2
Range	0 to 20 mA
Resolution	0.0003 mA
Accuracy	±0.3% of reading ±0.002 mA
Loop Compliance	1 Vdc at 20 mA
RTD Termination	
RTD Type	Pt1000
Range	-50 to 200 °C
Resolution	0.1 °C
Accuracy	±1 °C ± RTD accuracy
Discrete Input/Outputs	
Channels	2
Input/Output Voltage	0 to 32 Vdc
Input High Threshold	2.5 Vdc
Input Low Threshold	2.0 Vdc
Input Modes	State, Switch Closure, Pulse Count, Frequency
Switch Closure Freq.	100 Hz maximum
Pulse Count	65535 pulses per record
Frequency Input	65 kHz maximum, ±0.02% of reading ±1 Hz
Output Type	Open collector
Output Current	500 mA maximum
Output Modes	Remote On/Off, High Alarm, Low Alarm
Switched Power Ports	
Ports	2 switched battery
Output Current	500 mA maximum
Modes	Remote On/Off, Scheduled On/Off, On During Measure
Data Storage	
Memory Type	4 MB non-volatile flash
Data Record Size	1 to 64 registers (2 to 128 bytes)
Number of Data Records	131,008 (1 register per record, no encryption) to 25,216 (64 registers per record, with encryption)
Recording Rate	1 record per second with no wraparound 1 record per 5 seconds after wraparound
Recording Endurance	50,000 wraparound and erase cycles
Data Security	AES-128 Advanced Encryption Standard
Data Retention	10 years

Real-Time Clock	
Resolution	0.01 seconds
Accuracy	+/- 1 minute per month, temperature compensated
Backup Battery Life	10 years
Temperature Sensor	
Resolution	0.1 °C
Accuracy	+/- 3 °C
Voltage Sensor	
Resolution	0.01 Vdc
Accuracy	+/- 0.05 Vdc

5 Installation

5.1 Environmental Considerations

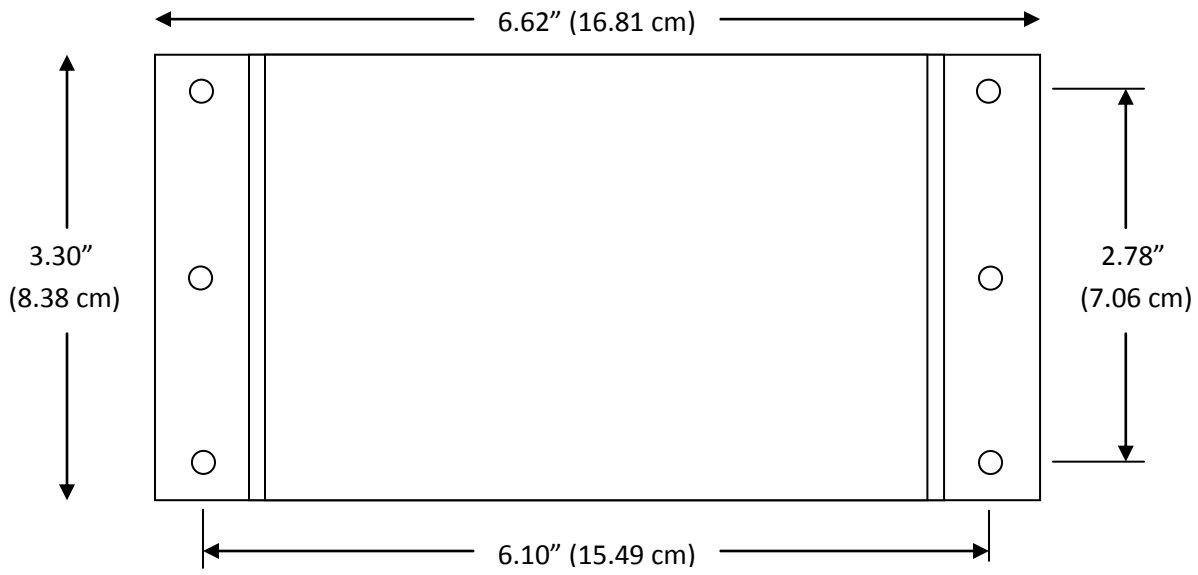
The PWS-600 is specified for operation in a non-condensing humidity environment. When temperature and/or humidity tolerances are exceeded, damage to internal components and/or measurement inaccuracies due to condensation may result.

The device must be housed in an enclosure suited for field use. The environmental ratings of the device's enclosure are intended as a backup to the primary field housing. The field housing should contain desiccant that is replaced or dried frequently enough to control the humidity. Effective control of the humidity is the user's responsibility.

Caution: If the battery charger is used, the field enclosure must be vented so that charge gasses from the battery do not accumulate. Failure to do so may present a risk of explosion.

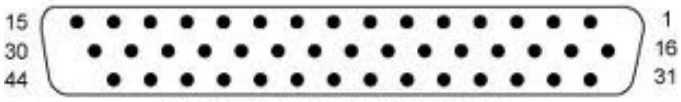
5.2 Mounting the Device

Mounting flanges are integral to the device's enclosure. Six mounting holes sized for #4 screws are provided. Two or more screws should be used to mount the enclosure.



5.3 Connector Pin-Out

The PWS-600 uses a standard 44-pin D-subminiature socket. The sockets on the face of the connector are numbered as shown below. This is also the pin-out looking at the wiring side of the mating 44-pin D-sub plug.



The function of each pin is described in the following table.

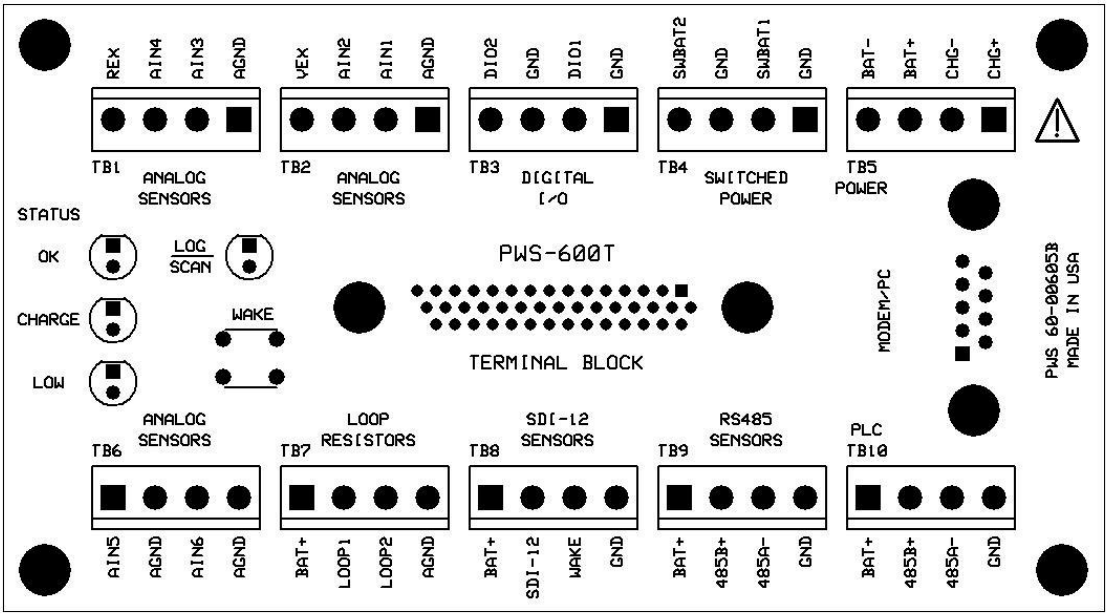
Pin	Name	Description
1	CTS	RS232 CTS output to pin 8 of a 9-pin D-sub plug
2	DTR	RS232 DTR input from pin 4 of a 9-pin D-sub plug
3	GND	RS232 GND to pin 5 of a 9-pin D-sub plug
4	CHG+	Positive side of solar panel charge input (parallel with pin 19)
5	CHG-	Negative side of solar panel charge input (parallel with pin 20)
6	BAT+	Positive side of battery or power input (parallel with pin 21)
7	BAT-	Negative side of battery or power input (parallel with pin 22)
8	SWBAT1	Switched power output 1 (parallel with pin 23)
9	SWBAT2	Switched power output 2 (parallel with pin 24)
10	DIO1	Discrete input/output port 1
11	DIO2	Discrete input/output port 2
12	LED_OK	Active low 10 mA constant current LED driver for OK status
13	LED_CHG	Active low 10 mA constant current LED driver for charge status
14	LED_LOW	Active low 10 mA constant current LED driver for low voltage status
15	LED_LOG	Active low 10 mA constant current LED driver for log/scan status
16	TXD	RS232 TXD input from pin 3 of a 9-pin D-sub plug
17	RXD	RS232 RXD output to pin 2 of a 9-pin D-sub plug
18	DCD	RS232 DCD output to pin 1 of a 9-pin D-sub plug
19	CHG+	Positive side of solar panel charge input (parallel with pin 4)
20	CHG-	Negative side of solar panel charge input (parallel with 5)
21	BAT+	Positive side of battery or power input (parallel with pin 6)
22	BAT-	Negative side of battery or power input (parallel with pin 7)
23	SWBAT1	Switched power output 1 (parallel with pin 8)
24	SWBAT2	Switched power output 2 (parallel with pin 9)
25	SDI-12 DATA	SDI-12 smart sensor network data line
26	VEX	Analog excitation voltage output
27	REX	Analog excitation resistor output
28	AIN5	Analog input 5
29	AIN3	Analog input 3
30	AIN1	Analog input 1

Pin	Name	Description
31	RTS	RS232 RTS input from pin 7 of a 9-pin D-sub plug
32	DSR	RS232 DSR output to pin 6 of a 9-pin D-sub plug
33	RI/5V	RS232 RI input/5V switched output to pin 9 of a 9-pin D-sub plug
34	WAKE	WAKE input
35	RS485A-	Master side RS485A- network input/output
36	RS485B+	Master side RS485B+ network input/output
37	SEN485A-	Smart sensor RS485A- network input/output
38	SEN485B+	Smart sensor RS485B+ network input/output
39	LOOP2	Current loop 2 resistor termination to GND
40	LOOP1	Current loop 1 resistor termination to GND
41	AGND	Analog ground reference
42	AIN6	Analog input 6
43	AIN4	Analog input 4
44	AIN2	Analog input 2

For reliability of the connection, the mating connector should utilize the mounting standoffs provided. The cable length should be kept as short as practical. The maximum length of cable for an RS485 network is 4000 feet (1200 meters). The maximum length of cable for an SDI-12 network is 200 feet (60 meters).

5.4 Terminal Block Accessory

The optional PWS-600T Terminal Block accessory board attaches to the 44-pin connector of the PWS-600 and provides terminal block connections for wiring all signals.



5.5 Power Requirements

The wide battery input voltage range of the PWS-600 permits operation on a 12 volt or 24 volt DC supply. The device will automatically shut down if the battery input voltage falls below 7 volts and will resume normal operation when the input voltage rises above 8 volts. Sustained operation above 32 volts will damage the device. The input is reverse polarity and transient protected. Connect the positive side of the battery or supply to the BAT+ terminal. Connect the negative side of the battery or supply to the BAT- terminal.

> *Caution: SDI-12 sensors generally do not operate across the same wide input voltage range as the PWS-600. The SDI-12 specification calls for a 12 volt DC supply that operates between 9.6 and 16 volts. Failure to observe the input voltage limits of a sensor can result in permanent damage to the sensor and/or the PWS-600.*

5.6 Charging Requirements

The PWS-600 contains a built-in charge controller for charging a 12 volt sealed lead acid (SLA) battery rated between 2.3 and 7.0 amp-hours.

> *Caution: Attempting to charge any battery type other than a 12 volt sealed lead acid battery may present an explosion hazard.*
>
> *Caution: Attempting to charge an SLA battery rated less than 2.3 amp-hours may cause the maximum battery charge current to be exceeded which can damage the battery and may present an explosion hazard.*
>
> *Caution: If the battery charger is used, the field enclosure must be vented so that charge gasses from the battery do not accumulate. Failure to do so may present a risk of explosion.*

Attempting to charge an SLA battery rated greater than 7.0 amp-hours may not fully charge the battery, reducing the battery life and leaving the system susceptible to brown-out conditions.

The charge controller is optimized for use with a solar panel in the 10 watt range with a 15 to 32 volt output; however, any comparable DC source, such as a mains connected DC power supply, can be used. Connect the positive side of the solar panel or charging supply to the CHG+ terminal. Connect the negative side of the solar panel or charging supply to the CHG- terminal.

If the charging feature is not required, the CHG terminals should be left unconnected. It is not recommended to use the charger without a battery – if a DC power supply is being used instead of a battery, it should be connected to the BAT terminals and the CHG terminals left unconnected. This will result in the lowest possible power consumption.

The charger input is reverse polarity and transient protected; however, sustained operation above 32 volts will damage the device. The charger output is protected against a reversed battery and battery voltages higher than 12 volts.

5.7 Status Indicators

The PWS-600 provides four system status indicators. The PWS-600T terminal block provides colored LED indicators. When power is applied to the device, all indicators will light in sequence as a lamp test. The status is then displayed for 30 seconds, after which the indicators are turned off to conserve power. Press the WAKE button to display the status for an additional 30 seconds.

> *Note: Jumper the WAKE terminal to GND to display status continuously. This can be useful in an industrial setting when power consumption is less of a concern, or when troubleshooting power problems.*

Three of the LED indicators provide power supply status as shown below.

ON: battery input above low threshold OFF: no charge input detected OFF: battery input above low threshold	OFF: battery input below low threshold OFF: no charge input detected ON: battery input below low threshold
ON: battery input above low threshold FLASHING: battery is charging OFF: no charge faults	ON: battery input above low threshold ON: battery is charged OFF: no charge faults
ON: battery input above low threshold ON: charge voltage detected ON: charging fault • charge input too low • temperature outside charge range • battery is not accepting charge	OFF: battery input below low threshold ON: charge voltage detected ON: charging fault • charge input too low • temperature outside charge range • battery is not accepting charge

The blue LED indicates the logging state of the device as shown below.

	OFF: Logging is disabled. The LED will pulse ON when a manual scan of the sensors is triggered.
	ON: Logging is enabled. The LED will pulse OFF when a log scan of the sensors triggered.
	FLASHING: Logging has been paused for a preset amount of time.

5.8 Communication

Communication with the data logger is done using the MODBUS serial line protocol over the RS485 or RS232 interface. The device is preconfigured with the MODBUS standard settings of 19200 baud, 8 data bits, even parity, 1 stop bit, RTU transmission mode, and device address 1.

5.8.1 RS485 Signals

RS485 communication is done using signals on terminal block TB10 labeled "PLC". Three signals are required to be connected to the master device: 485B+ is the positive transceiver signal, 485A- is the negative transceiver signal, and GND is the ground reference. No termination resistor is provided internally. In most applications, no termination resistor is necessary. If required, a resistor may be added externally. The maximum offset of the transceiver signals from GND 7 volts. Both signals are transient protected.

5.8.2 RS232 Signals

RS232 communication is done using the 9-pin D-sub connector labeled "MODEM/PLC". Connection to a PC or equivalent device requires the use of a null modem cable. Connection to a modem requires a regular straight-through cable.

6 Getting Started

The PWS-600 communicates as a slave device using the industry standard MODBUS protocol for serial devices. This section provides guidelines to getting the device up and running. If the device is not already wired, follow the installation instructions provided in the previous section.

Section 7 describes the device register map. The PWS-600 uses the MODBUS Holding Registers data model exclusively. All of the device functionality is accessed using the MODBUS read and write holding register commands.

Section 8 provides the details of the MODBUS protocol for users that are not familiar with MODBUS. Also refer to Section 8 for device-specific implementation information, such as the organization of registers into data types.

6.1 Device Configuration

Configuring the device consists of writing user-specific settings to one or more of the device registers. The Prairie View Software supplied with the device provides a convenient, step-by-step means to configure the device and is the recommended place to start. Refer to the software manual for instructions on installing the software on your desktop computer, laptop computer, or mobile device. It is also possible to configure the device by directly writing to the registers using a master device with pass-through capability, or using a third-party software tool.

6.2 Network Communication Settings

Before the device is placed on an active RS485 network, it must be configured to match the network's communication settings and be assigned a unique device address. The device is preconfigured with the MODBUS standard settings of 19200 baud, 8 data bits, even parity, 1 stop bit, RTU transmission mode, and device address 1. Refer to the Device Configuration section of the device register map to change the device address. Refer to the Communication Configuration Registers section of the device register map if any of the communication settings need to be changed.

6.3 Site Identification

If the user is collecting data from multiple devices located at different sites, it is recommended that the Site Id register be written with a unique value for each site. The Site Id is recorded with every data record, making it easier to track the data once it has been retrieved from a device.

6.4 Configure the Sensor Networks

Refer to section 7.5 to configure the sensor networks to match the sensor requirements. The Prairie View software helps to automate this process; however, the configuration registers can also be written directly using third-party software tools.

6.5 Configure the Data Log

The data log configuration registers must be programmed so that the PWS-600 will know how to acquire data from the sensors and at what interval, refer to section 7.6. The Prairie View software helps to automate this process; however, the configuration registers can also be written directly using third-party software tools.

Once the log is configured, set the Log Enable register to one to start logging. Data is then acquired and logged at the specified interval. The most recent acquisition from the sensors is available in the data log polling registers.

7 Register Map

The PWS-600 uses the MODBUS Holding Registers data model exclusively. All of the device functionality is accessed using the MODBUS read and write holding register commands. The organization of the register map is kept consistent among Prairie Wind System devices as much as practical.

7.1 Device Configuration Registers

The device configuration registers identify the device, its site location, and its basic configuration.

Device Configuration Registers					
Register Number	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
1000	1	USHORT	R	Register Map Version	2
1001	1	USHORT	R	Device Id	600
1002	2	ULONG	R	Serial Number	
1004	1	USHORT	R	Firmware Version	
1005	1	USHORT	R	Boot Code Version	
1006	1	USHORT	R	Hardware Version	
1007	1	USHORT	R/W	Site Id	0
1008	16	STRING	R/W	Site Name	0
1024	32	USHORT	R/W	Site Information	0
1056	1	USHORT	R/W	Device Address	1
1057	1	USHORT	R/W	Low Voltage Warning Threshold	9600 mV

7.1.1 Register Map Version

This is the version of the register map supported by the device. This provides for the modification of the register map at a future date and detection of the difference by the master device.

7.1.2 Device Id

This is the model number of the device. It can be used to validate the system configuration and to identify the available feature set.

7.1.3 Serial Number

This is the serial number of the device. The master device can read the serial number of the device to provide system traceability.

7.1.4 Firmware Version

This register identifies the firmware version of the device.

7.1.5 Boot Code Version

This register identifies the boot code version of the device. The boot code supports field upgrades of the device firmware. The boot code on a given device will not change with firmware upgrades. Its version is made available to support field upgrade utilities.

7.1.6 Hardware Version

This register contains the hardware version of the device.

7.1.7 Site Id

The Site Id is a general-purpose, non-volatile, read/write register. The contents of this register are recorded with each logged data record, permitting data to be traced to a particular site or system.

7.1.8 Site Name

The Site Name identifies the site to a user. The 16-register, non-volatile string holds up to 32 characters.

7.1.9 Site Information

Site Information is comprised of 32, general-purpose, non-volatile, read/write registers. Use these registers to hold system configuration and/or calibration data. The format of the data contained in the registers is defined by the user. They can be used as individual registers or combined to form ULONG, FLOAT or STRING data types. These registers should not be used to hold data that changes frequently.

7.1.10 Device Address

The device address is used to address the PWS-600 on the MODBUS network. The valid range for the device address is 1 to 247. The default value is 1. When this register is written, the response will be returned with the previous address. All subsequent commands must be sent with the new address. The register is non-volatile. The address is used on both the RS485 and RS232 interfaces.

7.1.11 Low Voltage Warning Threshold

If the battery input voltage to the device is less than or equal to this threshold, the low voltage warning status bit is set in the device status register. The threshold is set in millivolts and can range from 8000 to 32000 mV (8 to 32 volts). Attempting to write a value outside this range will generate an exception response with the ILLEGAL WRITE VALUE exception code. This threshold also used by the LED indicators to alert the user to a low battery.

7.2 Device Command Register

The device command register is used to issue commands to the device. The register is isolated from other registers in the register map to help prevent accidental writing.

Device Command Register					
Register Number	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
1065	1	USHORT	R/W	Device Command	0

Writing a value shown in the following table will issue the corresponding device command. Attempting to write any other value will generate an exception response with the ILLEGAL WRITE VALUE exception code. Reading the register always returns zero.

Device Commands		
Value	**Name**	**Description**
56573 (0xDCFD)	Factory Defaults	Resets device configuration registers to their factory default values. The encryption key is erased and encryption is disabled. Does not affect the communication settings, the data log or the diagnostic registers. This command is not allowed while data logging is enabled.
56557 (0xDCED)	Erase Data Log	Erases the data log. Data cannot be recovered after issuing this command. The response message is sent after erasure is complete. Typical response time is 30 seconds. The maximum response time is 90 seconds. Erasing the data log does not affect the current encryption key. This command is not allowed while data logging is enabled.
56541 (0xDCDD)	Download Data Log	Starts the fast data download process. The maximum response time to this command is 1000 milliseconds. Refer to the Data Retrieval Registers section for a description of the command.
56320 (0xDC00)	Security Mode	Places the device in the security mode, requiring a master device to log in with a password to regain access. The command has no effect if password security is disabled.
56480 (0xDCA0)	Read Sensors	Causes the PWS-600 to read data from its sensors immediately using the command sequence currently specified for data logging. Sensor values are placed in the last sensor reading registers but are not logged. The device status register should be monitored to determine when sensor values are valid.

Device Commands (continued)		
Value	**Name**	**Description**
56481 (0xDCA1)	SDI-12 Command	Sends the command contained in the SDI-12 pass-through registers to a sensor located on the SDI-12 network. The data log must be disabled or paused in order to use this command.
56482 (0xDCA2)	SDI-12 over RS485 Command	Sends the command contained in the SDI-12 pass-through registers to a sensor located on the SDI-12 network. The data log must be disabled or paused in order to use this command.
56482 (0xDCA2)	Clear Sensor Diagnostics	Clears sensor network message counters.

7.3 Device Status Registers

The device status registers allow the master device to obtain the current operating status of the device.

Device Status Registers					
Register Number	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
1070	1	USHORT	R/W	Device Status	0
1071	1	SHORT	R	Ambient Temperature	°C x 10
1072	1	USHORT	R	Input Voltage	mV
1073	1	USHORT	R	Charge Voltage	0 mV
1074	4	TIME	R/W	Date and Time	UTC

7.3.1 Device Status

This register contains device operational status. Each bit in the register represents a status value as defined in the following table.

Device Status Register			
Bit	**Mask**	**Name**	**Description**
0	0x0001	Power Outage	A power outage caused a hardware reset and recovery
1	0x0002	Low Voltage	The input voltage is below the warning threshold
2	0x0004	Clock Battery	Timekeeping backup battery is low
3	0x0008	Clock Fault	Timekeeping restarted at 2000-01-01 00:00:00.00
4	0x0010	Clock Adjusted	Date and Time were changed
5	0x0020	Device Fault	A device fault caused a reset and recovery
6	0x0040	Temperature	Device operating temperature range was exceeded
7	0x0080	Sensor Busy	Sensor command sequence is busy (new values are not valid)
8	0x0100	Encryption Enabled	Encryption key is non-zero, data records will be encrypted
9	0x0200	Reserved	Always returns 0
10	0x0400	Reserved	Always returns 0
11	0x0800	Reserved	Always returns 0
12	0x1000	Reserved	Always returns 0
13	0x2000	Reserved	Always returns 0
14	0x4000	Reserved	Always returns 0
15	0x8000	Reserved	Always returns 0

The status register is non-volatile: information is retained across a power outage. The status represents events that occurred since the last time the register was cleared. The device status is recorded with each logged data record. The status register can be cleared at any time by writing zero to it. Any conditions that persist or reoccur after being cleared will cause those bits to be set again. Attempting to

write any value other than zero to clear the register will generate an exception response with the ILLEGAL WRITE VALUE exception code.

7.3.2 Ambient Temperature

This register measures and returns the ambient temperature in degrees Celsius (°C) multiplied by 10. For example, an ambient temperature of 23.7 °C will be read as 237.

7.3.3 Input Voltage

This register measures and returns the battery input voltage applied to the device in millivolts (mV). For example, a battery input voltage of 13.54 volts will be read as 13540.

7.3.4 Charge Voltage

This register measures and returns the charging voltage applied to the device in millivolts (mV). For example, a charge input voltage of 19.76 volts will be read as 19760.

7.3.5 Date and Time

These registers hold the current date and time as a TIME data type. The device is programmed to Universal Coordinated Time (UTC) at the factory and generally does not need to be adjusted. If the clock should require adjustment, it is recommended that UTC continue to be used as the clock does not provide for automatic adjustments for local Daylight Savings Time. The time stamps of stored data may be post-processed to any local time as needed for reporting or analysis.

When setting the clock, the year must be in the range 2000 to 2399. Leap years in this range are correctly handled. Attempting to write an invalid date or time will generate an exception response with the ILLEGAL WRITE VALUE exception code. Setting the clock will clear the clock fault bit and set the clock adjusted bit in the status register.

7.4 Communication Configuration Registers

These registers specify the communication configuration of the master RS485 and RS232 ports.

Communication Configuration Registers					
Register Number	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
1101	1	USHORT	R/W	Communication Settings	276
1102	1	USHORT	R/W	Message Timeout (ms)	0
1103	1	USHORT	R/W	Sleep Timeout (ms)	0
1104	1	USHORT	R/W	Good Message Counter	0
1105	1	USHORT	R/W	Bad Message Counter	0
1106	1	USHORT	R/W	Exception Response Counter	0

7.4.1 Communication Settings

This register sets the communication parameters of the RS485 and RS232 ports. The default value is 276 (0x114) for RTU mode at 19200 baud, 8 bits, even parity, and 1 stop bit. The register is non-volatile.

Register Bits															
Reserved					Protocol			Stop	Parity		Data	Baud Rate			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
(default) RTU protocol					**0**	**0**	**1**								
ASCII protocol					0	1	0								
IP protocol					1	0	0								
(default) 1 stop bit								**0**							
2 stop bits								1							
(default) Even parity									**0**	**0**					
Odd parity									0	1					
No parity									1	0					
7 data bits											0				
(default) 8 data bits											**1**				
1200 baud												0	0	0	0
2400 baud												0	0	0	1
4800 baud												0	0	1	0
9600 baud												0	0	1	1
(default) 19200 baud												**0**	**1**	**0**	**0**
38400 baud												0	1	0	1
57600 baud												0	1	1	0

When this register is written, the response will be returned at the previous communication settings. All subsequent commands must be sent at the new settings. Attempting to write any combination of bits not listed in the above table will result in an exception response with the ILLEGAL WRITE VALUE exception code. Note that 7 data bits in the RTU transmission mode is an invalid combination; the device will respond with an exception and the ILLEGAL WRITE VALUE exception code.

7.4.2 Message Timeout

If RTU or IP is selected, this register specifies the amount of idle time that must elapse before the device recognizes the end of a message. A value of zero specifies a timeout that is selected automatically based on the selected baud rate as described in the RTU Message Format section. If the master device is unable to meet the default timing requirements, a fixed timeout from 5 to 50 milliseconds may be specified. The register is non-volatile.

If ASCII mode is selected, this register specifies the maximum time that may elapse between characters within a message when the ASCII transmission mode is selected. Intervals exceeding the timeout value will cause the device to assume an error has occurred and discard the message. The valid range for the timeout in ASCII mode is 1000 to 60000 milliseconds (1 to 60 seconds). The recommended setting for most applications is 1000 milliseconds.

7.4.3 Sleep Timeout

This register specifies the amount of time allowed to elapse with no network activity before the device enters its low power sleep mode. The valid range for the timeout is 0, or 1000 to 60000 milliseconds (1 to 60 seconds). A value of zero disables the low power sleep mode. The register is non-volatile.

After the device enters its sleep mode, any activity detected on the network will cause the device to wake; however, the contents of the first message will most likely be missed. If this first message was a command addressed to the device, the master device will receive no response and must retry the command. Afterwards, as long as there is network activity more frequent than the sleep timeout setting, the device will remain awake and process commands.

> *Note: The sleep timeout takes precedence over the message timeout. If the sleep timeout is used (non-zero) it should be set greater than or equal to the message timeout.*

7.4.4 Message Counters

The message counter registers provide diagnostic information for troubleshooting communication problems. Each counter is reset by writing it to zero. The counters roll back to zero after the maximum count value of 65535 is reached. The registers are volatile and will reset to zero if power is removed.

The Good Message Counter counts properly formatted messages that are addressed to the device. The Bad Message Counter tracks the number of improperly formatted messages, such as those with a bad CRC. The Exception Response Counter counts the number of messages received that were rejected with an exception response.

7.5 Sensor Networks

The PWS-600 uses the concept of sensor networks to organize its sensor data logging features. Four sensor networks are provided, numbered as shown below.

1 – RS485 Smart Sensor Network
2 – SDI-12 Smart Sensor Network
3 – Analog Sensor Network
4 – Discrete Sensor Network

Each sensor network has features common to all sensors on that network, and it is these features that are discussed in this section. The data log configuration sensor command group registers specify how to access and log sensors on a network.

7.5.1 RS485 Smart Sensor Network

RS485 sensor communication uses the signals on terminal block TB9, labeled "RS485 SENSORS". The terminal block provides terminals for power, ground, and the RS485 transceiver signals. 485B+ is the positive transceiver signal and 485A- is the negative transceiver signal. The 485B+ signal is provided with a 4.75K ohm resistor to the device's internal +3.3 volt supply. The 485A- signal is provided with a 4.75K ohm termination resistor to GND. No signal termination resistor is provided internally. In most low power applications, no additional termination resistor is necessary. If required, a resistor may be added externally. The maximum offset of the signals from the GROUND at pin 1 is 7 volts. Both signals are transient protected.

The RS485 sensor network can be configured to operate using one of three protocols: MODBUS RTU, MODBUS ASCII, or SDI-12. A group of eight registers define and configure the network protocol. These eight registers must be read and written within a single command. The format of these eight registers varies based on the selected network protocol. The register block may not be written when logging is enabled. Attempting to write the register block when logging is enabled will generate an exception response with the READ-ONLY REGISTER exception code.

7.5.1.1 MODBUS RTU Sensor Network Configuration

The following table defines the RS485 sensor network configuration registers when configured to use the MODBUS RTU protocol.

RS485 Sensor Network Configuration Group					
Register	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
1803	1	USHORT	R/W	Communication Settings	
1804	1	USHORT	R/W	Message Timeout (ms)	0
1805	1	USHORT	R/W	Network Wake Delay (ms)	0
1806	1	USHORT	R/W	Retries (0 to 5)	1
1807	1	USHORT	R/W	Sentinel Value	0xFFFF
1808	1	USHORT	R/W	Good Message Counter	0

1809	1	USHORT	R/W	Bad Message Counter	0
1810	1	USHORT	R/W	Exception Response Counter	0

7.5.1.2 Communication Settings

This register sets the protocol and the communication parameters for the network. Note that 7 data bits in the RTU transmission mode is an invalid combination; the device will respond with an exception and the ILLEGAL WRITE VALUE exception code.

Register Bits															
Protocol								Stop	Parity		Data	Baud Rate			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	1								
1 stop bit								0							
2 stop bits								1							
Even parity									0	0					
Odd parity									0	1					
No parity									1	0					
7 data bits											0				
8 data bits											1				
1200 baud												0	0	0	0
2400 baud												0	0	0	1
4800 baud												0	0	1	0
9600 baud												0	0	1	1
19200 baud												0	1	0	0
38400 baud												0	1	0	1
57600 baud												0	1	1	0

For example, to configure the network for MODBUS RTU at 19200 baud, 8 data bits, even parity, and 1 stop bit, set this register to 276.

7.5.1.3 Message Timeout

The message timeout register specifies the amount of idle time that must elapse before the device recognizes the end of an RTU message. The default value of zero signifies a timeout that is selected automatically based on the selected baud rate as described in the RTU Message Format section. If any slave device on the network is unable to meet the default timing requirements, a fixed timeout from 5 to 50 milliseconds may be specified. The default setting is zero.

7.5.1.4 Network Wake Delay

Some sensors may enter a low power mode if no network activity is detected for some period of time. While in this mode, the sensor may not respond immediately to the first command it receives. To accommodate sensors with this behavior, the device can be programmed to "wake" the sensor network before starting requests for data.

If the Network Wake Delay is set to a non-zero value, the device will broadcast a Report Slave Id command on the sensor network. This will generate network activity that will cause sensors to exit their low power mode. Because this is a broadcast of a read command, sensors should not respond to the command. The device will then delay the number of milliseconds specified by the Network Wake Delay register before requesting data from the sensors. If the Network Wake Delay is set to zero, this broadcast message is not sent.

7.5.1.5 Retries

This register specifies the number of times the device is to resend a command if a sensor does not respond within the timeout specified for that command. Zero specifies no retries; only one command attempt will be made. If the sensor fails to respond to a command after the allowed number of retries, the sensor will be considered unresponsive and the sentinel value will be substituted for all registers that were expected by the command.

7.5.1.6 Sentinel Value

The sentinel value is written in place of the data values for all registers that cannot be read by a command. This will occur if a sensor fails to respond to a read register command, or if the sensor returns an exception response.

7.5.1.7 Message Counters

The message counter registers provide diagnostic information for troubleshooting communication problems. Each counter is reset by writing it to zero. The counters roll back to zero after the maximum count value of 65535 is reached. The registers are volatile and will reset to zero if power is removed.

The Good Message Counter counts properly formatted messages that are returned to the device. The Bad Message Counter tracks the number of improperly formatted messages, such as those with a bad CRC. The Exception Response Counter counts the number of messages that were rejected with an exception response.

7.5.1.8 MODBUS ASCII Sensor Network Configuration

The following table defines the RS485 sensor network configuration registers when configured to use the MODBUS ASCII protocol.

RS485 Sensor Network Configuration Group					
Register Offset	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
1803	1	USHORT	R/W	Communication Settings	
1804	1	USHORT	R/W	Message Timeout (ms)	1000
1805	1	USHORT	R/W	Network Wake Delay (ms)	0
1806	1	USHORT	R/W	Retries (0 to 5)	1
1807	1	USHORT	R/W	Sentinel Value	0xFFFF
1808	1	USHORT	R/W	Good Message Counter	0
1809	1	USHORT	R/W	Bad Message Counter	0
1810	1	USHORT	R/W	Exception Response Counter	0

7.5.1.9 Communication Settings

This register sets the protocol and the communication parameters for the network.

Register Bits															
Protocol								Stop	Parity		Data	Baud Rate			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	1	0								
1 stop bit								0							
2 stop bits								1							
Even parity									0	0					
Odd parity									0	1					
No parity									1	0					
7 data bits											0				
8 data bits											1				
1200 baud												0	0	0	0
2400 baud												0	0	0	1
4800 baud												0	0	1	0
9600 baud												0	0	1	1
19200 baud												0	1	0	0
38400 baud												0	1	0	1
57600 baud												0	1	1	0

For example, to configure the network for MODBUS ASCII at 19200 baud, 8 data bits, even parity, and 1 stop bit, set this register to 532.

7.5.1.10 Message Timeout

The message timeout register specifies the maximum time that may elapse between characters within a message. Intervals exceeding the timeout value will cause the device to assume an error has occurred and discard the message. The valid range for the timeout is 1000 to 60000 milliseconds (1 to 60 seconds). The default setting is 1000 milliseconds.

7.5.1.11 Network Wake Delay

Some sensors may enter a low power mode if no network activity is detected for some period of time. While in this mode, the sensor may not respond immediately to the first command it receives. To accommodate sensors with this behavior, the device can be programmed to "wake" the sensor network before starting requests for data.

If the Network Wake Delay is set to a non-zero value, the device will broadcast a Report Slave Id command on the sensor network. This will generate network activity that will cause sensors to exit their low power mode. Because this is a broadcast of a read command, sensors should not respond to the command. The device will then delay the number of milliseconds specified by the Network Wake Delay register before requesting data from the sensors. If the Network Wake Delay is set to zero, this broadcast message is not sent.

7.5.1.12 Retries

This register specifies the number of times the device is to resend a command if a sensor does not respond within the timeout specified for that command. Zero specifies no retries; only one command attempt will be made. If the sensor fails to respond to a command after the allowed number of retries, the sensor will be considered unresponsive and the sentinel value will be substituted for all registers that were expected by the command.

7.5.1.13 Sentinel Value

The sentinel value is written in place of the data values for all registers that cannot be read by a command. This will occur if a sensor fails to respond to a read register command, or if the sensor returns an exception response.

7.5.1.14 Message Counters

The message counter registers provide diagnostic information for troubleshooting communication problems. Each counter is reset by writing it to zero. The counters roll back to zero after the maximum count value of 65535 is reached. The registers are volatile and will reset to zero if power is removed.

The Good Message Counter counts properly formatted messages that are returned to the device. The Bad Message Counter tracks the number of improperly formatted messages, such as those with a bad CRC. The Exception Response Counter counts the number of messages that were rejected with an exception response.

7.5.1.15 SDI-12 over RS485 Sensor Network Configuration

The following table defines the RS485 sensor network configuration registers when configured to use the SDI-12 protocol.

RS485 Sensor Network Configuration Group					
Register Offset	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
1803	1	USHORT	R/W	Communication Settings	2048
1804	1	USHORT	R/W	Break Retries (0 to 5)	2
1805	1	USHORT	R/W	Command Retries (0 to 5)	2
1806	2	FLOAT	R/W	Sentinel Value	99999
1808	1	USHORT	R/W	Good Message Counter	0
1809	1	USHORT	R/W	Bad Message Counter	0
1810	1	USHORT	R/W	Retry Counter	0

7.5.1.16 Communication Settings

This register sets the protocol and communication parameters for the network.

Register Bits															
Protocol								Stop	Parity		Data	Baud Rate			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	1	0	0	0								
1 stop bit								0							
Even parity									0	0					
7 data bits											0				
1200 baud												0	0	0	0

This register can only be written with a value of 2048 when the SDI-12 protocol is selected.

7.5.1.17 Retry Registers

These registers specify the number of times the device is to resend a break and command if an SDI-12 sensor does not respond within the required timeout. Zero specifies no retries; only one break and one command attempt will be made. If the sensor fails to respond to a command after the allowed number of retries, the sensor will be considered unresponsive and the SDI-12 sentinel value will be substituted for all values that were expected by the command.

Each break attempt is followed by the specified number of command attempts. For example, if break retries is set to 1 and command retries is set to 2:

1. The device will first send a break followed by the command.
2. If no response is received, the command will be retried two more times.

3. If still no response is received, the break will be retried, followed by three more attempts to send the command.
4. If still no response is received, all values that we expected to be received will be logged with the SDI-12 sentinel value.

7.5.1.18 Sentinel Value

The sentinel value is written in place of the measurement value for all sensor measurements that cannot be read by a command. This will occur if an SDI-12 sensor fails to respond to a command, or if a command is improperly structured to log more measurements than the sensor will return.

7.5.1.19 Message Counters

The message counter registers provide diagnostic information for troubleshooting communication problems. Each counter is reset by writing it to zero. The counters roll back to zero after the maximum count value of 65535 is reached. The registers are volatile and will reset to zero if power is removed.

The Good Message Counter counts properly formatted messages that are returned to the device. The Bad Message Counter tracks the number of improperly formatted messages, such as those with a bad CRC. The Exception Response Counter counts the number of messages that received no response.

7.5.2 SDI-12 Smart Sensor Network

The SDI-12 sensor network is a dedicated SDI-12 port that only supports the SDI-12 protocol. SDI-12 signals are available on terminal block TB8, labeled "SDI-12 SENSORS". Three signals are used for power, ground, and data. The data line is a bidirectional, tri-state signal using 5 volt logic that is capable of driving up to 10 SDI-12 sensors. The maximum length of cable between the PWS-600 and any SDI-12 sensor is 200 feet (60 meters).

A group of eight registers define and configure the network. These eight registers must be read and written within a single command. The register block may not be written when logging is enabled. Attempting to write the register block when logging is enabled will generate an exception response with the READ-ONLY REGISTER exception code.

SDI-12 Sensor Network Configuration Group					
Register Offset	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
1813	1	USHORT	R/W	Communication Settings	2048
1814	1	USHORT	R/W	Break Retries (0 to 5)	2
1815	1	USHORT	R/W	Command Retries (0 to 5)	2
1816	2	FLOAT	R/W	Sentinel Value	99999
1818	1	USHORT	R/W	Good Message Counter	0
1819	1	USHORT	R/W	Bad Message Counter	0
1820	1	USHORT	R/W	Retry Counter	0

7.5.2.1 Communication Settings

This register sets the protocol and communication parameters for the network. This register must be written with a value of 2048.

Register Bits															
Protocol								Stop	Parity		Data	Baud Rate			
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	1	0	0	0								
1 stop bit								0							
Even parity									0	0					
7 data bits											0				
1200 baud												0	0	0	0

7.5.2.2 Retry Registers

These registers specify the number of times the device is to resend a break and command if an SDI-12 sensor does not respond within the required timeout. Zero specifies no retries; only one break and one command attempt will be made. If the sensor fails to respond to a command after the allowed number of retries, the sensor will be considered unresponsive and the SDI-12 sentinel value will be substituted for all values that were expected by the command.

Each break attempt is followed by the specified number of command attempts. For example, if break retries is set to 1 and command retries is set to 2:

1. The device will first send a break followed by the command.
2. If no response is received, the command will be retried two more times.
3. If still no response is received, the break will be retried, followed by three more attempts to send the command.
4. If still no response is received, all values that we expected to be received will be logged with the SDI-12 sentinel value.

7.5.2.3 Sentinel Value

The sentinel value is written in place of the measurement value for all sensor measurements that cannot be read by a command. This will occur if an SDI-12 sensor fails to respond to a command, or if a command is improperly structured to log more measurements than the sensor will return.

7.5.2.4 Message Counters

The message counter registers provide diagnostic information for troubleshooting communication problems. Each counter is reset by writing it to zero. The counters roll back to zero after the maximum count value of 65535 is reached. The registers are volatile and will reset to zero if power is removed.

7.5.3 Analog Sensor Network

A group of eight registers define and configure the network. These eight registers must be read and written within a single command. The register block may not be written when logging is enabled. Attempting to write the register block when logging is enabled will generate an exception response with the READ-ONLY REGISTER exception code.

Analog Sensor Network Configuration Group					
Register Offset	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
1823	1	USHORT	R/W	Excitation Enable and Delay (ms)	0
1824	1	USHORT	R/W	Reserved	0
1825	1	USHORT	R/W	Reserved	0
1826	1	USHORT	R/W	Reserved	0
1827	1	USHORT	R/W	Reserved	0
1828	1	USHORT	R/W	Reserved	0
1829	1	USHORT	R/W	Reserved	0
1830	1	USHORT	R/W	Reserved	0

7.5.3.1 Excitation Enable and Delay

Some analog sensors require an excitation signal to be applied in order to make a measurement. The PWS-600 provides a voltage excitation (VEX) on terminal block TB2, and a resistive excitation (REX) on terminal block TB1. In order to conserve power, these excitation outputs are normally turned off. This register specifies how long to allow sensor outputs to stabilize after turning on excitation before taking analog measurements. The delay is specified in milliseconds and can range from 0 to 65535 milliseconds. The amount of delay will have an impact on the fastest log interval that can be achieved. Setting this register to zero disables excitation outputs (they will not be turned on during measurements).

7.5.4 Discrete Sensor Network

The discrete sensor network requires no configuration at this time. A group of eight registers is reserved to support future configuration options. These eight registers must be read and written within a single command. The register block may not be written when logging is enabled. Attempting to write the register block when logging is enabled will generate an exception response with the READ-ONLY REGISTER exception code.

Discrete Sensor Network Configuration Group					
Register Offset	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
1833	1	USHORT	R/W	Reserved	0
1834	1	USHORT	R/W	Reserved	0
1835	1	USHORT	R/W	Reserved	0
1836	1	USHORT	R/W	Reserved	0
1837	1	USHORT	R/W	Reserved	0
1838	1	USHORT	R/W	Reserved	0
1839	1	USHORT	R/W	Reserved	0
1840	1	USHORT	R/W	Reserved	0

7.6 Data Log Configuration Registers

These registers set the polling and data log schedule. All data log configuration registers are non-volatile.

Data Log Configuration Registers					
Register Number	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
1500	1	USHORT	R/W	Log Enable (0 = disabled, 1 = enabled)	0
1501	1	USHORT	R/W	Log Pause (seconds)	0
1502	4	TIME	R	Next Scheduled Record	UTC
1506	1	USHORT	R/W	Log Interval (seconds)	3600
1507	1	USHORT	R/W	Log Offset (seconds)	0
1508	1	USHORT	R/W	Number of Sensor Commands (0 to 32)	0
1509	8	USHORT	R/W	Sensor Command 1	
1517	8	USHORT	R/W	Sensor Command 2	
1525	8	USHORT	R/W	Sensor Command 3	
1533	8	USHORT	R/W	Sensor Command 4	
1541	8	USHORT	R/W	Sensor Command 5	
1549	8	USHORT	R/W	Sensor Command 6	
1557	8	USHORT	R/W	Sensor Command 7	
1565	8	USHORT	R/W	Sensor Command 8	
1573	8	USHORT	R/W	Sensor Command 9	
1581	8	USHORT	R/W	Sensor Command 10	
1589	8	USHORT	R/W	Sensor Command 11	
1597	8	USHORT	R/W	Sensor Command 12	
1605	8	USHORT	R/W	Sensor Command 13	
1613	8	USHORT	R/W	Sensor Command 14	
1621	8	USHORT	R/W	Sensor Command 15	
1629	8	USHORT	R/W	Sensor Command 16	
1637	8	USHORT	R/W	Sensor Command 17	
1645	8	USHORT	R/W	Sensor Command 18	
1653	8	USHORT	R/W	Sensor Command 19	
1661	8	USHORT	R/W	Sensor Command 20	
1669	8	USHORT	R/W	Sensor Command 21	
1677	8	USHORT	R/W	Sensor Command 22	

Data Log Configuration Registers					
Register Number	Size (Registers)	Data Type	Access	Name	Default Value
1685	8	USHORT	R/W	Sensor Command 23	
1693	8	USHORT	R/W	Sensor Command 24	
1701	8	USHORT	R/W	Sensor Command 25	
1709	8	USHORT	R/W	Sensor Command 26	
1717	8	USHORT	R/W	Sensor Command 27	
1725	8	USHORT	R/W	Sensor Command 28	
1733	8	USHORT	R/W	Sensor Command 29	
1741	8	USHORT	R/W	Sensor Command 30	
1749	8	USHORT	R/W	Sensor Command 31	
1757	8	USHORT	R/W	Sensor Command 32	

7.6.1 Log Enable

This non-volatile register can be set to one of the following values. Attempting to write any other value will result in an exception response with the ILLEGAL WRITE VALUE exception code.

0: Data log disabled. The next scheduled record registers will return zero. The data log configuration can be edited.

1: Data log enabled. The next scheduled record registers will return the date and time of the next scheduled log record per the defined schedule. Data log configuration registers are read-only and cannot be edited.

Attempting to write a log configuration register while the data log is enabled or paused will result in an exception response with the READ-ONLY REGISTER exception code.

7.6.2 Log Pause

Use this register to pause the data log for a specified period of time, such as when pass-through access to a sensor is necessary for calibration or maintenance. This register can only be written when the data log is enabled. When the data log is disabled, this register will return zero.

Writing a value from 1 to 65535 will pause the data log for the specified number of seconds. While paused, the next scheduled record registers will return zero, the data log configuration registers remain read-only and cannot be edited, and pass-through communication is enabled. Data logging will resume when the master device sets Log Pause back to zero, or will resume automatically when Log Pause counts down to zero.

Attempting to write a log configuration register while the data log is enabled or paused will result in an exception response with the READ-ONLY REGISTER exception code.

7.6.3 Next Scheduled Record

These registers return the date and time of the next scheduled record. These registers return zero if the log is disabled or paused.

7.6.4 Log Interval

The log interval specifies the time between data records in seconds. The log interval can range from 0 to 43200 seconds (12 hours or 2 records per day) and must specify a whole number of records per day. Setting the log interval to zero specifies an interval of 86400 seconds (24 hours or 1 record per day). Attempting to write a value that would not result in a whole number of records per day will result in an exception response with the ILLEGAL WRITE VALUE exception code.

Data records are synchronized with the real-time clock. The first data record each day is always collected at 00:00:00 plus the log offset value. If, for example, the log interval is set to 21600 seconds (6 hours) and the log offset is zero, the PWS-600 will log 4 records per day at 00:00:00, 06:00:00, 12:00:00, and 18:00:00.

7.6.5 Log Offset

The log offset specifies the offset of the first record from 00:00:00 each day. The offset is specified in seconds and can range from 0 to one second less than the log interval. Attempting to write a value outside this range will result in an exception response with the ILLEGAL WRITE VALUE exception code.

> *Note: If writing a new log interval would cause the log offset value to become invalid, the log offset will be automatically reset to zero.*

The log offset provides some flexibility in synchronizing daily data records with other system activities. For example, if the log interval is set to 21600 seconds (6 hours) and the log offset is set to 7200 seconds (2 hours), the PWS-600 will still collect 4 records per day, but the records will be offset to 02:00:00, 08:00:00, 14:00:00, and 20:00:00.

7.6.6 Number of Sensor Commands

This register specifies the number of sensor commands that will be used to read data from the sensors. Up to 32 commands can be used to read up to 64 registers. Sensor commands are executed sequentially beginning with sensor command 1. If zero is specified, no commands will be executed; only local parameters (time, site id, device id, device serial number, device status, ambient temperature, and input voltage) will be recorded.

7.6.7 Sensor Command Groups

Each sensor command (1 to 32) consists of a group of 8 registers. Each register in the following table is an offset from the first register of the sensor command group as specified in the Data Log Configuration Registers Table.

Sensor Command Group					
Register Offset	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
0	1	USHORT	R/W	Sensor Network (1-4)	
1 – 7	7	---	R/W	(sensor network protocol dependent)	---

All 8 registers in a group must be read and written within a single command. The first register in each command group specifies the sensor network on which the sensor is located. The RS485 smart sensor network is sensor network 1, the SDI-12 smart sensor network is sensor network 2, the analog sensor network is network 3, and the discrete network is network 4. The function of the remaining registers in each command group varies depending on the configuration of the selected network.

> *Note: changing the sensor network selection may cause other settings in the command group to become invalid due to a change in the network protocol. Configure sensor networks before selecting a sensor network.*

7.6.8 MODBUS Command Group Format

The following table defines the sensor command group for a smart sensor network configured to use a MODBUS protocol (RTU or ASCII). Each register in the table is an offset from the first register of the sensor command group as specified in the Data Log Configuration Registers Table.

Sensor Command Group					
Register Offset	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
0	1	USHORT	R/W	Sensor Network (network 1 only)	1
1	1	USHORT	R/W	Sensor Address (1 to 247)	1
2	1	USHORT	R/W	Data Type (1 to 4)	3
3	1	USHORT	R/W	Start Register Number (1 to 65535)	1
4	1	USHORT	R/W	Number of Registers (1 to 64)	1
5	1	USHORT	R/W	Response Timeout (milliseconds)	1000
6	1	USHORT	R/W	Reserved	0
7	1	USHORT	R/W	Reserved	0

Each sensor command generates a MODBUS read command for the specified data type. The data read from the sensor are added to the current data record. If several non-sequential registers or data types need to be read from a sensor, multiple read register commands can be sent to the same sensor.

7.6.8.1 MODBUS Sensor Address

This register specifies the sensor's network address.

7.6.8.2 MODBUS Data Type

This register specifies the data type to be read from the sensor according to the following table.

MODBUS Sensor Command Data Types	
Register Value	**MODBUS Data Type**
1	Coils
2	Discrete Inputs
3	Holding Registers
4	Input Registers

The default value is 3, to read holding registers. Attempting to write a value not in the table will result in an exception response with the ILLEGAL WRITE VALUE exception code.

7.6.8.3 MODBUS Start Register Number

For coils (1) and discrete input (2) data types, this register specifies the first coil or discrete input to read.

For holding register (3) and input register (4) data types, this register specifies the first register number to read.

7.6.8.4 MODBUS Number of Registers

For coils (1) and discrete input (2) data types, this register specifies the number of coils or discrete inputs to read. Each coil or discrete input is represented as a single bit and is packed 16 bits per register in the data record, beginning at the least significant bit of each register.

For holding register (3) and input register (4) data types, this register specifies the number of registers to read. Each register read is added sequentially to the data record.

A maximum of 64 registers can be specified across all read register commands. If the sensor returns an exception to the Read Registers command, the sentinel value will be recorded for each requested register.

7.6.8.5 MODBUS Response Timeout

The response timeout specifies the maximum amount of time the device should allow for the sensor to make a measurement and respond to the command. If a response is not received within the specified timeout, the device will retry the command if specified. If no response is received after the specified number of retries, the sentinel value will be recorded for each requested register.

7.6.9 SDI-12 Command Group Format

The following table defines the sensor command group for a smart sensor network configured to use the SDI-12 protocol. Each register in the table is an offset from the first register of the sensor command group as specified in the Data Log Configuration Registers Table.

SDI-12 Sensor Command Group					
Register Offset	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
0	1	USHORT	R/W	Sensor Network (1 or 2 in SDI-12 mode)	1
1	1	USHORT	R/W	Sensor Address	48
2	1	USHORT	R/W	Measurement Command	0
3	2	ULONG	R/W	Measurement Selection Bit Mask	1
5	1	USHORT	R/W	Reserved	0
6	1	USHORT	R/W	Reserved	0
7	1	USHORT	R/W	Reserved	0

Each sensor command generates the specified measurement command, reads the sensor response, then adds a FLOAT type value to the current data record for each selected measurement.

7.6.9.1 SDI-12 Sensor Address

This register specifies the sensor's network address. SDI-12 addresses are ranges of ASCII characters as defined in the following table. Address "0" is the default sensor address initially set by the manufacturer as defined by the SDI-12 specification. All sensors are required to support the address range "0" to "9". The other address ranges are optional and might not be supported by all sensors.

SDI-12 Sensor Address Ranges			
ASCII	**Decimal**	**Hexadecimal**	**Description**
"0"	48	0x30	Default
"1" to "9"	49 to 57	0x31 to 0x39	Standard Support
"A" to "Z"	65 to 90	0x41 to 0x5A	Optional Support
"a" to "z"	97 to 122	0x61 to 0x7A	Optional Support

Attempting to write any other value will result in an exception response with the ILLEGAL WRITE VALUE exception code.

7.6.9.2 SDI-12 Measurement Command

This register specifies the measurement command to be sent to the sensor. The device supports all of the standard SDI-12 measurement commands as outlined in the following table.

SDI-12 Measurement Command Table		
Register Value	**SDI-12 Command**	**Description**
0	"M"	Start measurement
1 to 9	"M1" to "M9"	Start additional measurement
10	"MC"	Start measurement with CRC
11 to 19	"MC1" to "MC9"	Start additional measurement with CRC
20	"C"	Start concurrent measurement
21 to 29	"C1" to "C9"	Start concurrent additional measurement
30	"CC"	Start concurrent measurement with CRC
31 to 39	"CC1" to "CC9"	Start concurrent additional measurement with CRC
40 to 49	"R0" to "R9"	Read continuous measurement
50 to 59	"RC0" to "RC9"	Read continuous measurement with CRC

Attempting to write any other value will result in an exception response with the ILLEGAL WRITE VALUE exception code.

7.6.9.3 SDI-12 Measurement Selection Bit Mask

This 32-bit register specifies which measurements returned by the sensor are to be logged. Bit 0 corresponds to the first measurement returned. Bit 31 corresponds to the 32nd measurement returned. Any bit set to a one selects the corresponding measurement to be logged. Any bit set to a zero will cause the corresponding measurement to be discarded.

> *Note: Version 1.3 of the SDI-12 specification limits the number of measurements returned by a sensor in response to a given measurement command to a maximum of 20. Future versions of the specification may increase this limit. The PWS-600 will support up to 32 measurement values from a sensor, allowing for some future expansion.*

For example, a sensor returns three parameters A, B, and C, to measurement command "M" and the measurement selection bit mask is set to 5 (binary 00000000 00000101). Measurements A and C will be logged, and measurement B will be discarded.

If a sensor does not return enough measurements to match a set bit, the SDI-12 sentinel value will be recorded in place of the measurement. For example, if a sensor returns three parameters to a measurement command A, B, and C, and the measurement selection bit mask is set to 13 (binary 00000000 00001101), measurements A and C will be logged, measurement B will be discarded, and the SDI-12 sentinel value will be logged in place of the missing 4th measurement.

7.6.10 Analog Command Group Format

The following table defines the sensor command group for an analog sensor network. Each register in the table is an offset from the first register of the sensor command group as specified in the Data Log Configuration Registers Table.

Analog Sensor Command Group					
Register Offset	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
0	1	USHORT	R/W	Sensor Network (network 3 only)	3
1	1	USHORT	R/W	Analog Channel (1 to 49)	
2	1	USHORT	R/W	Measurements to Average (1 to 25)	
3	1	USHORT	R/W	Output Format	0
4	2	FLOAT	R/W	Scale Factor (measurement units/mV)	1.0
6	2	FLOAT	R/W	Offset (measurement units)	0.0

7.6.10.1 Analog Channel

This register specifies the analog channel to be measured. An analog channel defines the physical analog inputs to be used for the measurement, as well as preconfigured ranges and functions.

Channel	+Input	-Input	Range	Description
1	ANI1	AGND	0 to 5000 mV	Single-ended, consider BAT+ or SWBATx for power
2	AIN2	AGND	0 to 5000 mV	Single-ended, consider BAT+ or SWBATx for power
3	AIN3	AGND	0 to 5000 mV	Single-ended, consider BAT+ or SWBATx for power
4	AIN4	AGND	0 to 5000 mV	Single-ended, consider BAT+ or SWBATx for power
5	AIN5	AGND	0 to 5000 mV	Single-ended, consider BAT+ or SWBATx for power
6	AIN6	AGND	0 to 5000 mV	Single-ended, consider BAT+ or SWBATx for power
7	ANI1	AGND	0 to 2000 mV	Single-ended, consider BAT+ or SWBATx for power
8	AIN2	AGND	0 to 2000 mV	Single-ended, consider BAT+ or SWBATx for power
9	AIN3	AGND	0 to 2000 mV	Single-ended, consider BAT+ or SWBATx for power
10	AIN4	AGND	0 to 2000 mV	Single-ended, consider BAT+ or SWBATx for power
11	AIN5	AGND	0 to 2000 mV	Single-ended, consider BAT+ or SWBATx for power
12	AIN6	AGND	0 to 2000 mV	Single-ended, consider BAT+ or SWBATx for power
13	ANI1	AGND	0 to 1000 mV	Single-ended, consider BAT+ or SWBATx for power
14	AIN2	AGND	0 to 1000 mV	Single-ended, consider BAT+ or SWBATx for power
15	AIN3	AGND	0 to 1000 mV	Single-ended, consider BAT+ or SWBATx for power
16	AIN4	AGND	0 to 1000 mV	Single-ended, consider BAT+ or SWBATx for power
17	AIN5	AGND	0 to 1000 mV	Single-ended, consider BAT+ or SWBATx for power
18	AIN6	AGND	0 to 1000 mV	Single-ended, consider BAT+ or SWBATx for power

Channel	+Input	-Input	Range	Description
19	ANI1	AGND	0 to 500 mV	Single-ended, consider BAT+ or SWBATx for power
20	AIN2	AGND	0 to 500 mV	Single-ended, consider BAT+ or SWBATx for power
21	AIN3	AGND	0 to 500 mV	Single-ended, consider BAT+ or SWBATx for power
22	AIN4	AGND	0 to 500 mV	Single-ended, consider BAT+ or SWBATx for power
23	AIN5	AGND	0 to 500 mV	Single-ended, consider BAT+ or SWBATx for power
24	AIN6	AGND	0 to 500 mV	Single-ended, consider BAT+ or SWBATx for power
25	AIN2	AIN1	±2000 mV	Differential, consider VEX & AGND for excitation
26	AIN4	AIN3	±2000 mV	Differential, consider VEX & AGND for excitation
27	AIN6	AIN5	±2000 mV	Differential, consider VEX & AGND for excitation
28	AIN2	AIN1	±1000 mV	Differential, consider VEX & AGND for excitation
29	AIN4	AIN3	±1000 mV	Differential, consider VEX & AGND for excitation
30	AIN6	AIN5	±1000 mV	Differential, consider VEX & AGND for excitation
31	AIN2	AIN1	±500 mV	Differential, consider VEX & AGND for excitation
32	AIN4	AIN3	±500 mV	Differential, consider VEX & AGND for excitation
33	AIN6	AIN5	±500 mV	Differential, consider VEX & AGND for excitation
34	AIN2	AIN1	±250 mV	Differential, consider VEX & AGND for excitation
35	AIN4	AIN3	±250 mV	Differential, consider VEX & AGND for excitation
36	AIN6	AIN5	±250 mV	Differential, consider VEX & AGND for excitation
37	AIN2	AIN1	±125 mV	Differential, consider VEX & AGND for excitation
38	AIN4	AIN3	±125 mV	Differential, consider VEX & AGND for excitation
39	AIN6	AIN5	±125 mV	Differential, consider VEX & AGND for excitation
40	AIN2	AIN1	±60 mV	Differential, consider VEX & AGND for excitation
41	AIN4	AIN3	±60 mV	Differential, consider VEX & AGND for excitation
42	AIN6	AIN5	±60 mV	Differential, consider VEX & AGND for excitation
43	AIN2	AIN1	±30 mV	Differential, consider VEX & AGND for excitation
44	AIN4	AIN3	±30 mV	Differential, consider VEX & AGND for excitation
45	AIN6	AIN5	±30 mV	Differential, consider VEX & AGND for excitation
46	AIN5	AGND	0 to 20.5 mA	Current loop, jumper AIN5 to LOOP1, consider BAT+ or SWBATx for power
47	AIN6	AGND	0 to 20.5 mA	Current loop, jumper AIN6 to LOOP2, consider BAT+ or SWBATx for power
48	AIN4	AGND	-50 to 200 °C	2-wire Pt1000 Platinum RTD, jumper AIN4 to REX One wire to AIN4, one wire to AGND
49	AIN4	AIN3	-50 to 200 °C	4-wire Pt1000 Platinum RTD, jumper AIN5 to REX Power pair to AIN5 and AGND Sense pair to AIN4 and AIN3

7.6.10.2 Measurements to Average

This register specifies the number of consecutive channel measurements to average. The number of readings averaged will have an impact on the fastest log interval that can be achieved. Setting this register to one disables averaging.

7.6.10.3 Output Format

The output format specifies how the sensor measurement is formatted and added to the current data record.

Output Format	
Value	**Description**
0	USHORT (1 register)
1	SHORT (1 register)
2	FLOAT (2 registers)

The internal measurement result is a floating point value; specifying a FLOAT output places the measurement result directly into the current data record as a FLOAT.

If an USHORT value is specified, the floating point value is rounded to an unsigned integer value in the range 0 to 65535. If the rounded value is greater than 65535, 65535 is output. If the rounded value is less than zero, then zero is output.

If a SHORT value is specified, the floating point value is rounded to a signed integer value in the range -32768 to +32767. If the rounded value is greater than +32767, +32767 is output. If the rounded value is less than -32768, -32768 is output.

7.6.10.4 Scale Factor and Offset

The scale factor and offset can be used to convert the measured value to the appropriate sensor parameter units according to the following equation:

Measured Output = Scale Factor (Measured Value) + Offset

The scale factor and offset are applied before conversion to one of the short formats occurs. Note also that the platinum RTD channels provide temperature in Celsius units. Scaling is only necessary to convert units or improve the resolution when using one of the integer formats.

7.6.11 Discrete Command Group Format

The following table defines the sensor command group for a discrete sensor network. Each register in the table is an offset from the first register of the sensor command group as specified in the Data Log Configuration Registers Table.

Discrete Sensor Command Group					
Register Offset	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
0	1	USHORT	R/W	Sensor Network	
1	1	USHORT	R/W	Discrete Channel	
2	1	USHORT	R/W	Reserved	0
3	1	USHORT	R/W	Output Format	0
4	2	FLOAT	R/W	Scale Factor (measurement units/mV)	1.0
6	2	FLOAT	R/W	Offset (measurement units)	0.0

7.6.11.1 Discrete Channel

This register specifies the discrete channel to be measured. A discrete channel defines the physical discrete inputs to be used for the measurement, as well as preconfigured ranges and functions.

Channel	Input	Description
1	DIO1	Input state (0 or 1)
2	DIO2	Input state (0 or 1)
3	DIO1	Positive edge debounced switch counter, counts up to 65535 switch closures between log records, resets back to zero after record is logged
4	DIO2	Positive edge debounced switch counter, counts up to 65535 switch closures between log records, resets back to zero after record is logged
5	DIO1	Negative edge debounced switch counter, counts up to 65535 switch closures between log records, resets back to zero after record is logged
6	DIO2	Negative edge debounced switch counter, counts up to 65535 switch closures between log records, resets back to zero after record is logged
7	DIO1	Pulse counter, counts up to 65535 pulses between log records, resets back to zero after record is logged
8	DIO2	Pulse counter, counts up to 65535 pulses between log records, resets back to zero after record is logged
9	DIO1	Frequency counter, 1 second gate measures from 1 to 65535 Hz.
10	DIO2	Frequency counter, 1 second gate measures from 1 to 65535 Hz.

7.6.11.2 Output Format

The output format specifies how the sensor measurement is formatted and added to the current data record.

Output Format	
Value	**Description**
0	USHORT (1 register)
1	SHORT (1 register)
2	FLOAT (2 registers)

The internal measurement result is a floating point value; specifying a FLOAT output places the measurement result directly into the current data record as a FLOAT.

If an USHORT value is specified, the floating point value is rounded to an unsigned integer value in the range 0 to 65535. If the rounded value is greater than 65535, 65535 is output. If the rounded value is less than zero, then zero is output.

If a SHORT value is specified, the floating point value is rounded to a signed integer value in the range -32768 to +32767. If the rounded value is greater than +32767, +32767 is output. If the rounded value is less than -32768, -32768 is output.

7.6.11.3 Scale Factor and Offset

The scale factor and offset can be used to convert the measured value to the appropriate sensor parameter units according to the following equation:

Measured Output = Scale Factor (Measured Value) + Offset

The scale factor and offset are applied before conversion to one of the short formats occurs.

7.6.12 Last Sensor Readings

These registers allow a master device to read the last sensor readings. The last sensor readings may be generated by the last log record, or by the read sensors device command. The format of the data registers is determined by the sensor command groups. These registers are not encrypted. The registers are volatile and will reset to zero if power is removed.

Last Data Log Record Registers					
Register Number	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
2300	4	TIME	R	Date and Time	
2304	1	USHORT	R	Site Id	
2305	1	USHORT	R	Device Id	
2306	2	ULONG	R	Device Serial Number	
2308	1	USHORT	R	Device Status	
2309	1	SHORT	R	Ambient Temperature	°C x 10
2310	1	USHORT	R	Input Voltage	mV
2311	1	USHORT	R	Register Count	
2312	64	USHORT	R	Data Registers	

7.7 Switched Power Outputs

The PWS-600 provides two switched battery outputs labeled SWBAT1 and SWBAT2. Each output is capable of switching up to 0.5 amperes and can be programmed to turn on during the measurement time to power sensors, or programmed to turn on and off on a daily schedule to power a radio or cellular modem for remote access.

A third switched power output is available on the RS232 connector on pin 9. This +5V, 275 mA supply can be used to power master-side RS232 communication accessories such as a modem or Ethernet adapter.

Switched Power Output Registers					
Register Number	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
2401	1	USHORT	R	Switched Output Status	0
2402	11	USHORT	R/W	Switched Output SWBAT1 Configuration	
2413	11	USHORT	R/W	Switched Output SWBAT2 Configuration	
2424	11	USHORT	R/W	RS232 +5V Switched Output Configuration	

7.7.1 Switched Output Status

This read-only register provides the status of each of the switched outputs.

Switched Output Status Register															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
reserved		reserved		reserved		reserved		reserved		RS232 +5V		SWBAT2		SWBAT1	

Each switched output is described by a pair of bits, indicating its current output state. The status of unsupported (reserved) switched outputs will always be indicated as off.

Switched Output States	
Bits	Description
00	Off
01	Fault (output shorted or overloaded)
10	Marginal (output < 90% of expected)
11	On

7.7.2 Switched Power Output Configuration

The following table defines the switched power output configuration group. Each register in the table is an offset from the first register in the group as specified in the Switched Power Output Registers Table. Registers in this group may be accessed individually or as a group.

Switched Power Output Configuration Group					
Register Offset	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
0	1	USHORT	R/W	Switched Output Mode	0
1	1	USHORT	R/W	Measurement Warm-up Delay (ms)	0
2	9	USHORT	R/W	Switched Output Schedule	0

7.7.2.1 Switched Output Modes

The output mode specifies how the switched power output will be controlled.

Output Mode	
Value	**Description**
0	Always Off
1	On to Measure
2	On by Schedule
3	Always On

When "On to Measure" is selected, the device will turn on the switched power output prior to taking a sensor measurement of any kind, wait the specified measurement delay, and then take the measurements specified by the log commands. This mode is used to control power to sensors that draw too much current to be left on continuously.

When "On by Schedule" is selected, the device will turn the switched power output on and off as specified by the schedule register bits, independent of the log schedule. In this mode, the measurement warm-up delay is not used. This mode may be used to control external interface equipment, such as a cellular modem, that may draw too much power to be left on continuously.

"On Always" turns the output on continuously. Combined with the "Off" mode, this mode permits remote control or test of a switched power output.

7.7.2.2 Switched Output Schedule

These nine registers comprise 144 bits, each representing a 10 minute interval of the day. Bit 0 of the first register (offset 2) represents 00:00:00 to 00:09:59. Bit 15 of the last register (offset 10) represents 23:50:00 to 23:59:59. For each bit that is set, the output will be turned on during the corresponding 10 minute interval each day. The following table illustrates the bit mapping of the schedule registers.

Switched Output Schedule Register Bit Start Times (UTC)						
Register Offset	**Bit 15**	**Bit 12**	**Bit 9**	**Bit 6**	**Bit 3**	**Bit 0**
2	02:30	02:00	01:30	01:00	00:30	00:00
3	05:10	04:40	04:10	03:40	03:10	02:40
4	07:50	07:20	06:50	06:20	05:50	05:20
5	10:30	10:00	09:30	09:00	08:30	08:00
6	13:10	12:40	12:10	11:40	11:10	10:40
7	15:50	15:20	14:50	14:20	13:50	13:20
8	18:30	18:00	17:30	17:00	16:30	16:00
9	21:10	20:40	20:10	19:40	19:10	18:40
10	23:50	23:20	22:50	22:20	21:50	21:20

As an example, it is desired to have a cellular modem on from 12:00 to 1:00 P.M. (12:00 to 13:00) each day, Mountain Standard Time (MST). Since MST is UTC – 6 hours, that corresponds to 18:00 to 19:00 UTC. Set bits 12 through 15 of register offset 8 (61440 or 0xF000) and bits 0 through 1 of register offset 9 (3 or 0x0003).

7.8 Discrete Outputs

The two discrete I/O terminals on the PWS-600 can be used as inputs or outputs. This section describes how to program the discrete I/O as outputs. When programmed as an output, the discrete cannot be used as an input.

Discrete Output Registers					
Register Number	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
2501	1	USHORT	R	Discrete Output Status	0
2502	6	USHORT	R/W	Discrete Output 1 Configuration	
2508	6	USHORT	R/W	Discrete Output 2 Configuration	

7.8.1 Discrete Output Status

This read-only register provides the status of each of the discrete outputs. Each discrete output is described by a single bit, indicating its current output state (0 = off, 1 = on). The status of unsupported outputs will always be indicated as off.

Discrete Output Status Register															
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	DIO2	DIO1

7.8.2 Discrete Output Configuration

The following table defines the discrete output configuration group. Each register in the table is an offset from the first register in the group as specified in the Discrete Output Registers Table. Registers in this group may be accessed individually or as a group.

Discrete Output Configuration Group					
Register Offset	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
0	1	USHORT	R/W	Discrete Output Mode	0
1	1	USHORT	R/W	Data Record Offset (0 to 63)	0
2	1	USHORT	R/W	Data Record Data Type	0
3	2	FLOAT	R/W	Alarm Threshold	0
5	1	USHORT	R/W	Hysteresis (0 to 10% in 0.1% increments)	0

7.8.2.1 Discrete Output Modes

The output mode specifies how the discrete output will be controlled.

Output Mode	
Value	**Description**
0	Always Off
1	High Alarm
2	Low Alarm
3	Always On

When "High Alarm" is selected, the device will turn on the discrete output if the assigned logged value is greater than or equal to the programmed alarm threshold. The output will be turned off when the assigned logged value returns below the alarm threshold minus the hysteresis setting.

When "Low Alarm" is selected, the device will turn on the discrete output if the assigned logged value is less than or equal to the programmed alarm threshold. The output will be turned off when the assigned logged value returns above the alarm threshold plus the hysteresis setting.

"On Always" turns the output on continuously. Combined with the "Off" mode, this mode permits remote control or test of a discrete output.

7.8.2.2 Data Record Offset

This register specifies the offset into the last logged record where the logged value resides. The offset must be aligned with a valid log value in order for the alarm value comparison to be valid.

7.8.2.3 Data Record Data Type

This register specifies the data type of the logged value pointed to by the data record offset. The data type must match the type of the recorded value in order for the alarm value comparison to be valid. The logged value will be converted to a floating point value for comparison to the alarm threshold.

Data Types	
Value	**Description**
0	USHORT (1 register)
1	SHORT (1 register)
2	FLOAT (2 registers)

7.8.2.4 Alarm Threshold

This register specifies the alarm threshold. It must be of the same units and scaling as the recorded log value.

7.8.2.5 Hysteresis

Hysteresis can range from 0.0 to 10.0% of the alarm threshold and is specified in 0.1% increments. For example, 2.5% is written as 25. Adding hysteresis prevents chatter of the discrete output if the logged value is moving slowly about the alarm threshold.

7.9 Data Log Recording Registers

These registers configure data log security and allow the MODBUS master device to record additional information in the data log such as user notes.

Data Log Recording Registers					
Register Number	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
1300	8	STRING	W	Encryption Key	
1320	1	USHORT	W	Register Count	
1321	64	USHORT	W	Data Registers	

7.9.1 Encryption Key

Write this 8-register string to set a 128-bit encryption key. Afterwards, all data records written to the data log will be encrypted using this key. The registers are write-only so that the key is protected. The registers are non-volatile, so the key need only be written once prior to recording data. When shipped from the factory or after a factory defaults command is issued, the key is erased and encryption is disabled. Issuing a factory defaults command does not remove encryption from data already stored in the data log.

It is recommended that the user not mix data recorded with different encryption keys, or mix encrypted and unencrypted data in the same log, as this will make decrypting the log difficult. Changing the encryption key does not change the encryption of previously recorded data. The data log should be erased prior to, or immediately after, changing the encryption key.

> ***Note: It is the responsibility of the user to manage encryption keys. Once written, the encryption key cannot be read out of the device. Once data is recorded with encryption, it cannot be decrypted without the original key.***

7.9.2 Recording Data

Data is recorded in the data log using the following procedure.

1. Write the number of registers to be recorded (1 to 64) to register 1320. Attempting to write a value outside this range will result in an exception response with the ILLEGAL WRITE VALUE exception code.

2. Write data registers beginning at register 1321. Only the number of data registers specified by the register count can be written. Attempting to write more data registers than specified by the register count will result in an exception response with the ILLEGAL ADDRESS VALUE exception code. A single Write Multiple Registers function can be used to write the register count and the data registers in one transaction.

3. When the last data register is written as determined by the register count, the device will write the record to the data log along with the time, site id, device id, device serial number, device status, ambient temperature, and input voltage. The typical response time to this write is less than 100 milliseconds. The maximum response time is 3 seconds.

The register count and data registers are write-only to protect unencrypted data from being read.

One of the primary purposes of allowing the MODBUS master device to write data asynchronously to the logged sensor data is to be able to insert notes. Notes can be in any suitable format (ASCII, packed ASCII, Unicode, etc.); however, for easy decoding of the log data, the record size (register count) of the notes should be something different than the record size of the sensor data records. Assigning note records to a constant size of 64 registers is recommended. If the defined STRING data type is used, this allows notes to be up to 128 characters long.

7.9.3 Recording Speed

The PWS-600 is capable of recording data as fast as 1 record per second provided that the data log has not wrapped around. Once the data log has wrapped around, the recording rate drops to 1 record every 5 seconds. This is necessary in order to provide time for block erasures when the oldest data is erased.

In addition, the log configuration settings must be considered. The response timeout value and the number of retries will affect the maximum recording speed.

7.10 Data Log Retrieval Registers

These registers allow a master device to retrieve data records from the data log.

Data Log Retrieval Registers					
Register Number	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
1400	2	ULONG	R	Data Log Size (bytes)	4,194,304
1402	2	ULONG	R	Data Log Used (bytes)	0
1404	2	ULONG	R	Lowest Record Number	0
1406	2	ULONG	R	Highest Record Number	0
1408	1	USHORT	R/W	Download Record Count	0
1409	2	ULONG	R/W	Record Number	0
1411	1	USHORT	R	Record Size in Registers	0
1412	4	TIME	R	Date and Time	0
1416	1	USHORT	R	Site Id	0
1417	1	USHORT	R	Device Id	0
1418	2	ULONG	R	Device Serial Number	0
1420	1	USHORT	R	Device Status	0
1421	1	SHORT	R	Ambient Temperature	°C x 10
1422	1	USHORT	R	Input Voltage	mV
1423	1	USHORT	R	Register Count	0
1424	64	USHORT	R	Data Registers	0
1488	4	USHORT	R	Encryption Padding Registers	

7.10.1 Data Log Size

This register returns the data log memory size in bytes.

7.10.2 Data Log Used

This register returns the number of data log memory bytes currently used. Combined with the data log size, the register can be used to calculate the percent of memory used and percent of memory remaining.

7.10.3 Lowest and Highest Record Numbers

If no records have been logged, both the lowest and highest record numbers will be zero. Records are numbered beginning at record one. The highest record number will increment with each record logged (the highest record number is also the total number of records recorded since the log was last erased). As long as the data log hasn't wrapped, the lowest record number will remain at one. Once the log wraps around, the lowest record number will begin to advance as the oldest data is deleted. Every record will have a unique and always increasing number. If the user keeps track of the last record number that was retrieved, only higher record numbers will need to be retrieved at the next download.

7.10.4 Download Record Count

This register specifies the maximum number of records to transfer when the Data Log Download command is used. The default value of zero permits continuous streaming of data records. This record is non-volatile. The content of this register has no effect when reading data records via the Data Log Retrieval registers.

7.10.5 Record Number

Write this register to specify the data record number to read. If the write is successful, the remaining registers are filled in with the record data and are ready to be read. The average response time is 500 milliseconds seconds. The maximum response time is 1000 milliseconds.

Attempting to write a record number less than the lowest record number or greater than the highest record number will result in an exception response with the ILLEGAL WRITE VALUE exception code.

If a data record is found to be corrupt the device will return an exception response with the CORRUPT DATA RECORD exception code. As much of the data record will be retrieved as possible; however, the register count and/or contents of the record are suspect. If the register count returns zero, the record could not be retrieved. A corrupt record can occur if power fails during the time the data record is being written.

7.10.6 Record Size

After writing the record number, this register provides the size of the record in registers. The size includes all registers from the first register of the time stamp to the last data register.

7.10.7 Record Data

After writing the record number, the record data registers can be read. All data registers may be read, including those beyond the record size. This permits the master device to read all of the data record registers with one command regardless of the record size. Only the data registers specified by the register count will contain valid information.

If the data is unencrypted, the register numbers and sizes shown in the table above can be read to extract portions of the data record if not all of the information is needed.

If the data is encrypted, reading individual registers from the table will not be useful. A read registers command must be used to read the number of registers specified by the record size. All of the registers in the record are required in the decryption process.

The unencrypted record format for logged data is the same as that described for the data polling registers.

7.10.8 Data Decryption

The Prairie View Software that comes with the device provides data decryption and the capability to view and export data from encrypted logs.

The Advanced Encryption Standard is supported by many operating systems, so it is possible for user applications and third-party software to decrypt logs, providing that the original encryption key is known.

7.10.9 Data Retrieval Procedure

The following procedure describes data retrieval using conventional MODBUS register read and write commands.

1. The master device reads the lowest and highest record number registers to determine the valid record number range and selects the range of records to be downloaded.

2. The master device writes a record number to the record number register. The PWS-600 retrieves the record from the data log.

3. The master device reads the record size register to determine the number of registers in the record.

4. The master device reads the number of registers specified by the size registers beginning with the time register.

5. Optionally, after the master device has written the record number, it can simply read all record registers from the register size through the encryption padding registers and decode the record later.

6. The master device repeats steps 2 through 6 until all selected records have been retrieved.

7.10.10 Data Log Download Command

The following procedure describes the use of the data log download command. This command provides considerably faster downloads as compared to conventional register access.

1. The master device reads the lowest and highest record number registers to determine the valid record number range.

2. The master device writes the first record number to be downloaded to the record number register. To download all data, set the record number register equal to the lowest record number. The PWS-600 has a maximum response time of 1000 milliseconds to this command.

3. The master device writes the data log download command to the command register. The PWS-600 will return a standard response to this write register command with a maximum response time of 1000 milliseconds.

4. After a 500 millisecond delay, the PWS-600 will begin to stream the number of records specified by the download record count, beginning at the record specified by the record number register. If the download record count is set to zero, the download will continue uninterrupted to the highest record number. Each record is constructed as a standard MODBUS read registers response that begins at the record number register and contains all registers in the record. There will be little or no delay between records.

5. After all records have been sent, the PWS-600 will send an exception response with the END DOWNLOAD exception code.

6. The master device must be capable of receiving records back-to-back until it detects the END DOWNLOAD exception.

The user should consider the following when using this command to download data.

- There is no handshaking. The master device must be capable of receiving records back-to-back with little or no delay between records. Since the record number is included in each record sent and each record contains a CRC or LRC, the master device can determine if any records were missed.

- On the RS485 port, there is no way to cancel the command. The PWS-600 will stream data until it is done. The network is unavailable for any other communication until the download is finished.

- If the PWS-600 encounters a corrupt record during the download, it will send an exception response with the CORRUPT DATA RECORD exception code in place of the corrupt record and the download will continue.

7.10.11 Last Data Log Record

These registers allow a master device to read the last data record from the data log directly. The format and encryption requirements are the same as those for a retrieved record.

Last Data Log Record Registers					
Register Number	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
2200	2	ULONG	R/W	Record Number	
2202	1	USHORT	R	Record Size in Registers	
2203	4	TIME	R	Date and Time	
2207	1	USHORT	R	Site Id	
2208	1	USHORT	R	Device Id	
2209	2	ULONG	R	Device Serial Number	
2211	1	USHORT	R	Device Status	
2212	1	SHORT	R	Ambient Temperature	°C x 10
2213	1	USHORT	R	Input Voltage	mV
2214	1	USHORT	R	Register Count	
2215	64	USHORT	R	Data Registers	
2279	4	USHORT	R	Encryption Padding Registers	

The last data log record is only valid while data logging is enabled. If the data log is disabled, or if no data record has been recorded since the data log was enabled, the record number will return zero to indicate that the remaining record data is not valid.

7.11 Sensor Network Pass-Through Registers

The PWS-600 supports pass-through from its communication port network to a sensor network to assist in the configuration and maintenance of connected sensors.

Sensor Network Pass-Through Registers					
Register Number	Size (Registers)	Data Type	Access	Name	Default Value
2000	1	USHORT	R/W	Sensor Network	0
2001	64	USHORT	R/W	Command/Response string	0

7.11.1 Sensor Network

This non-volatile register selects the sensor network for pass-through. Setting this register to zero disables pass-through communication. The data log must be disabled or paused in order to use pass-through commands.

7.11.2 MODBUS Protocol Pass-Through

If the selected sensor network is configured for a MODBUS protocol, the PWS-600 passes any MODBUS command on its communication port that is not addressed to the PWS-600 itself to the sensor network, and will pass back the sensor response. The sensor will appear as if it resides on the master network. If the MODBUS protocol or communication setting of the sensor network differs from that of the communication port, the device will translate messages accordingly.

7.11.3 SDI-12 Protocol Pass-Through

If the selected sensor network is configured for the SDI-12 protocol, the master device must utilize the SDI-12 Command/Response registers and device command to generate a pass-through message and receive the response.

The command and response string is treated as a packed ASCII STRING data type as described in the Data Types section of the manual; however individual registers are read/write accessible so that only the required registers need to be written or read instead of the entire contents of the string.

Use the following procedure to pass an SDI-12 command to a sensor and obtain the response.

1. Write the packed ASCII command beginning at register 2001. Each register contains two ASCII characters, with the upper byte of the register holding the leading character. The command must begin with the SDI-12 address, and end with the "!" character. No other validation of the command format is performed, allowing sensor-specific extended commands to be sent.

2. Write device command 56481 to the device command register to send the command to a sensor on the SDI-12 network. All characters up to and including the "!" character will be sent. If the "!" character is not found in the string, the command will not be sent.

3. The Sensor Busy bit in the Device Status register can be monitored to determine when the command/response cycle is finished. Generally, the response of the SDI-12 sensor is faster than the sensor busy status can be checked, allowing this step to be skipped.

4. The device returns the sensor response in the command/response string beginning at register 1801. The original command is overwritten. All characters returned by the sensor, up to and including the carriage return and line feed character are provided. Character positions following the line feed character are padded with zeroes. If no response is received from the sensor, the entire string will be filled with zeroes.

7.12 Password Security Registers

Additional module security is available by enabling password protection. When a security password is written to the PWS-600, the master device must log in with the correct password in order to access any of the device registers. When the device is secure, only the read slave id function and the write to the login password registers are possible.

Data Log Retrieval Registers					
Register Number	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
3000	10	STRING	W	Security Password	0
3010	10	STRING	W	Login Password	0

7.12.1 Security Password

This ten-register, non-volatile, register string sets the password for the device. By default, the registers are set to zero, disabling password protection. The device slave id and all device registers are open and accessible.

Writing a 10-register, non-zero password to these registers enables password security. If no communication port activity is detected after a period of 60 seconds, or if the Security Mode device command (56320) is issued, the device will enter its secure mode. In the security mode, only the slave id and the login password registers are available. Attempting to perform any other function while in the security mode will result in an exception response with the SECURITY MODE exception code.

> ***Note: It is the responsibility of the user to manage passwords. Once written, the security password cannot be read out of the device. Once the device is secured with a password, it cannot be accessed without the original password.***

7.12.2 Login Password

Writing a 10-register password that matches the Security Password will temporarily take the device out of the security mode. Logging in with a password that does not match the security password will result in an exception response with the ILLEGAL WRITE VALUE exception code and, if the device is in the security mode, the device will remain in the security mode.

7.13 Diagnostic Registers

These registers provide device diagnostic and troubleshooting information.

Device Description					
Register Number	**Size (Registers)**	**Data Type**	**Access**	**Name**	**Default Value**
9000	1	USHORT	R	Configuration Flash Writes.	< 50,000
9001	1	USHORT	R	Last Reset Type	0
9002	1	USHORT	R	Fault Count	0
9003	1	USHORT	R	Last Fault Type	0
9004	1	USHORT	R	Last Fault Information	0
9005	1	SHORT	R	High Temperature	°C x 10
9006	1	SHORT	R	Low Temperature	°C x 10
9007	1	USHORT	R	Data Log Chip Id	8214 or 9538
9008	1	USHORT	R	Data Log Erasure Count	< 50,000

7.13.1 Configuration Flash Writes

This non-volatile register records the number of times the device configuration registers have been written to. Since these registers are intended for occasional configuration of the device, a high number indicates frequent changes and possibly improper use of the registers.

7.13.2 Last Reset Type

This register records information about the last reset event that caused the power outage bit to be set in the device status register.

Reset Types	
Type	**Description**
0	None recorded
1	Power outage detected by the CPU – power lost and restored
2	Brownout detected by CPU – marginal power source (e.g. very low battery)
3	Brownout detected by the timekeeping circuit – marginal power source

7.13.3 Fault Information

These registers record information about the last fault event that caused the device fault bit to be set in the device status register. The fault count records the number of fault events. An occasional fault may indicate a normal recovery from an unusual power loss sequence or transient event. Frequent faults may indicate hardware damage or a firmware defect.

Fault Types	
Type	**Description**
0	None recorded
4	Invalid interrupt, last fault information register updated with interrupt number
5	Memory access violation
6	Watchdog timeout

7.13.4 High and Low Temperatures

These registers record the ambient temperature extremes (in degrees Celsius multiplied by 10) experienced by the device.

7.13.5 Data Log Chip Id

This register reports the identification of the internal data log chip. The value may be any one of the values listed in the table.

7.13.6 Data Log Erasure Count

This non-volatile register records the number of times the data log has wrapped around and/or has been erased.

8 MODBUS Protocol

The PWS-600 utilizes the MODBUS over Serial Line protocol for communication over an RS485 network.

The MODBUS Serial Line protocol is a half-duplex, master-slave protocol. One master device controls the network or link, and is connected to one or more slave devices. A MODBUS transaction is always initiated by the master device. Slave devices never transmit data without first receiving a request from the master device. Slave devices never communicate with each other. The master device only initiates one MODBUS transaction with one slave device at a time. The PWS-600 implements the functions of a slave device in the protocol.

The MODBUS standard defines two serial transmission modes: RTU mode and ASCII mode. All devices connected to a network must be configured to use the same transmission mode and communication parameters. This device supports both transmission modes.

8.1 RTU Transmission Mode

The MODBUS RTU (Remote Terminal Unit) transmission mode is an 8-bit byte-oriented binary protocol with timing-based message framing. The RTU mode is the default transmission mode for the device.

8.1.1 RTU Character Format

The standard format for each character in an RTU message is as follows.

1	2	3	4	5	6	7	8	9	10	11
Start	Bit 0	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Parity	Stop

The 11-bit character is sent least-significant bit first, left to right as shown, with 1 start bit, 8 data bits, a parity bit, and one stop bit. The default parity of the device is even parity. Odd parity and no parity are also supported.

When no parity is specified, 2 stop bits should be used so that the 11-bit character size is maintained:

1	2	3	4	5	6	7	8	9	10	11
Start	Bit 0	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Stop	Stop

8.1.2 RTU Message Format

An RTU message is comprised of a sequence of 4 to 256 characters transmitted in a continuous stream. No more than 1.5 character times should be permitted between the characters in a message. The format of a message is as follows.

Slave Address	Function Code	Data	CRC
1 byte	1 byte	0 to 252 bytes	2 bytes

By default, for baud rates less than or equal to 19200, an idle time of 3.5 character times signifies the end of a message. For baud rates higher than 19200, an idle time of 1.75 milliseconds signifies the end of a message.

The RTU mode uses a Cyclical Redundancy Check (CRC) to provide error checking across a message, from the slave address to the last data byte. Only the eight data bits of each character are used in generating the CRC; start and stop bits and the parity bit do not apply. The CRC field is a 16-bit value. The low-order byte is appended first, followed by the high-order byte. The high-order byte of the CRC is the last byte in the message. A slave device will not act on or respond to a message that has an invalid CRC or parity errors. The master device must discard a slave response with an invalid CRC or parity errors and either resend the message or generate an error.

Techniques for calculating the CRC can be found in the document *MODBUS over Serial Line Specification and Implementation Guide V1.02*, available at modbus-ida.org.

8.2 ASCII Transmission Mode

In the MODBUS ASCII transmission mode, each 8-bit byte in a message is sent as two hexadecimal ASCII characters. The message is also framed with unique ASCII characters. This mode is preferred when the communication link cannot guarantee the inter-character timing required by the RTU mode, such as a packet-based wireless link.

8.2.1 ASCII Character Format

The standard format for each character in an RTU message is as follows.

1	2	3	4	5	6	7	8	9	10
Start	Bit 0	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Parity	Stop

The 10-bit character is sent least-significant bit first, left to right as shown, with 1 start bit, 7 data bits, a parity bit, and one stop bit. The default parity of the device is even parity; odd parity and no parity are also supported.

When no parity is specified, 2 stop bits should be used so that the 10-bit character size is maintained:

1	2	3	4	5	6	7	8	9	10
Start	Bit 0	Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Stop	Stop

Although not specified by the MODBUS standard, the PWS-600 will also support the ASCII mode using 8-bit characters with or without parity as described for the RTU mode.

8.2.2 ASCII Message Format

An ASCII message is comprised of a sequence of 9 to 513 characters. The format of a message is as follows.

Start	Slave Address	Function Code	Data	LRC	End
1 char ':'	2 chars (1 byte)	2 chars (1 byte)	0 to 504 chars (0 to 254 bytes)	2 chars	2 chars CR, LF

The ASCII colon character ":" begins a message. The message ends with the ASCII control characters carriage return (CR) and line feed (LF). The byte information of an ASCII message from the slave address to the end of the data is identical to that of an RTU message. Each byte of the message is transmitted as two ASCII hexadecimal characters 0-9, A-F.

By default, intervals up to one second may elapse between characters within the message. The device supports a programmable timeout interval up to 60 seconds. Intervals exceeding the timeout value will cause the device to assume an error has occurred and discard the message. Each reception of a colon character signals the beginning of a new message. If a message was in the process of being received when a colon is received, the previous message will be discarded.

The ASCII mode uses a Longitudinal Redundancy Check (LRC) to provide error checking across a message, from the slave address to the last data byte. The beginning colon and ending CR-LF pair are not included in the calculation. Only the data bits of each character are used in generating the LRC; start and stop bits and the parity bit do not apply. The LRC is an 8-bit value, encoded with two ASCII characters in the same manner as a data byte. A slave device will not act on or respond to a message that has an invalid LRC or parity errors. The master device must discard a slave response with an invalid LRC or parity errors and either resend the message or generate an error.

Techniques for calculating the LRC can be found in the document *MODBUS over Serial Line Specification and Implementation Guide V1.02*, available at modbus-ida.org.

8.3 MODBUS IP

This device also supports the MODBUS IP protocol on its master-side RS485 port. It is provided to support cases where a companion gateway or modem does not support translation between MODBUS IP and either MODBUS RTU or MODBUS ASCII. An IP message is essentially a MODBUS RTU message with an extended header.

Transaction Id	Protocol Id	Length	Slave Address	Function Code	Data
2 bytes	2 bytes	2 bytes	1 byte	1 byte	0 to 252 bytes

The transaction id identifies a MODBUS command/response transaction. It is uniquely set by the master device and echoed by the slave device.

The protocol id specifies the transaction protocol. It must always be set to zero to specify MODBUS.

The length field specifies the length of the remaining bytes in the packet, including the slave address, function code, and data.

8.4 Device Addressing

The MODBUS master device has no specific address, only the slave devices have an address. Each slave device on a network must be assigned a unique address. Slave addresses can range from 1 to 247. Address 0 is reserved as the broadcast address. The device will recognize the broadcast address as well as its own address. No response is returned to broadcast requests.

8.5 Data Types

The MODBUS Protocol defines four primary data models: Discrete Inputs, Coils, Input Registers, and Holding Registers. The PWS-600 uses the Holding Registers model exclusively.

MODBUS uses big endian representation for register numbers and data items – when a numerical quantity larger than a single byte is transmitted, the most significant byte is sent first. Register data are packed as two bytes per register, the first byte contains the high order bits and the second byte contains the low order bits.

The device extends the big endian representation to data types requiring multiple registers. The first register contains the high order bytes and subsequent registers contain the lower order bytes.

8.5.1 USHORT: Unsigned Short

An unsigned short is a 16-bit unsigned integer value in the range 0 to 65535. The value is contained in a single register. This is the basic MODBUS holding register data type.

Register	
Byte 1	Byte 2
Bits 15 - 8	Bits 7 - 0

8.5.2 SHORT: Signed Short

A signed short is a 16-bit two's complement signed integer value in the range -32768 to +32767. The value is contained in a single register.

Register	
Byte 1	Byte 2
Sign, Bits 14 - 8	Bits 7 - 0

8.5.3 ULONG: Unsigned Long

An unsigned long is a 32-bit unsigned integer value contained in two consecutive registers. Values can range from 0 to 4,294,967,295.

Register		Register + 1	
Byte 1	Byte 2	Byte 3	Byte 4
Bits 31 - 24	Bits 23 - 16	Bits 15 - 8	Bits 7 - 0

8.5.4 LONG: Signed Long

A signed long is a 32-bit two's complement signed integer value contained in two consecutive registers. Values can range from -2147483648 to +2147483647.

Register		Register + 1	
Byte 1	Byte 2	Byte 3	Byte 4
Sign, Bits 30 - 24	Bits 23 - 16	Bits 15 - 8	Bits 7 - 0

8.5.5 FLOAT: Floating Point

A float is a 32-bit IEEE-754 floating point value contained in two consecutive registers.

Register		Register + 1	
Byte 1	Byte 2	Byte 3	Byte 4
SXXXXXXX	XMMMMMMM	MMMMMMMM	MMMMMMMM

S is the sign bit, X is the 8-bit exponent, and M is the 23-bit mantissa.

8.5.6 STRING: Character String

A string is a sequence of consecutive registers where each byte within a register represents an 8-bit ASCII-encoded character. A string of N characters requires N / 2 registers. When reading or writing a string, all characters in the string must be transmitted. If the string to be written does not require the full available length, the unused characters must be padded with zeroes.

Register	
Byte 1	Byte 2
Character 1	Character 2

Register + 1	
Byte 1	Byte 2
Character 3	Character 4

.
.
.

Register + (N / 2) – 1	
Byte 1	Byte 2
Character N - 1	Character N

8.5.7 TIME: Date and Time

Time is represented by 16 packed BCD digits contained in 4 consecutive registers. The registers are organized with the most significant temporal digit first, ranging from 1000 years to 0.01 seconds. Only BCD digits '0' to '9' are used. Time is in the 24-hour format.

Register			
Byte 1		Byte 2	
1000 years	100 years	10 years	Year

Register + 1			
Byte 1		Byte 2	
10 Months	Month	10 Days	Day

Register + 2			
Byte 1		Byte 2	
10 Hours	Hour	10 Minutes	Minutes

Register + 3			
Byte 1		Byte 2	
10 Seconds	Seconds	0.1 Seconds	0.01 Seconds

8.6 Function Codes

The MODBUS Protocol defines a variety of standard function codes for reading and writing data to a device. Only the function codes described in this section are supported by the device. All other function codes will generate an exception response with the ILLEGAL FUNCTION exception code.

8.6.1 Report Slave Id

This function code is used to read the device description. All of the device-specific information is also available in the register map and is detailed in that section.

Command			
Byte Offset	Field Description	Type	Value
0	Device Address	BYTE	1-247
1	Function Code	BYTE	17 (0x11)

Response			
Byte Offset	Field Description	Type	Value
0	Device Address	BYTE	1-247
1	Function Code	BYTE	17 (0x11)
2	Byte Count	BYTE	18
3	Slave Id	BYTE	80 (0x50) 'P'
4	Run Status Indicator	BYTE	255 (0xFF) = ON
5	Slave Id Version	USHORT	1
7	Device Id	USHORT	600
9	Serial Number	ULONG	
13	Firmware Version	USHORT	
15	Boot Code Version	USHORT	
17	Hardware Version	USHORT	
19	Register Map Version	USHORT	

The response to a slave id command is typically returned in less than 50 milliseconds.

8.6.2 Read Registers

This function code is used to read the contents of a contiguous block of registers.

Command			
Byte Offset	Field Description	Type	Value
0	Device Address	BYTE	1-247
1	Function Code	BYTE	3 (0x03)
2-3	Starting Register Address	USHORT	0-65535 (0xFFFF)
4-5	Number of Registers (N)	USHORT	1-125 (0x007D)
6	CRC Low	BYTE	
7	CRC High	BYTE	

Response			
Byte Offset	Field Description	Type	Value
0	Device Address	BYTE	1-247
1	Function Code	BYTE	3 (0x03)
2	Byte Count	BYTE	2 x N
3	Register Data	2 x N BYTES	

The starting register address is one less than the starting register number. The byte count returned will be two times the number of registers read.

- If the Read Registers function code is used to read data from a single register, the single register must be a single-register data type such as a USHORT. An attempt to read a single register from within a multiple-register data type will result in an exception response with the ILLEGAL DATA ADDRESS exception code.

- If the Read Registers function code is used to read a multiple-register data type, the start register address must be of the first register in the field and the number of registers must include all registers in the field. If one or both parameters are invalid, the device will return an exception response with the ILLEGAL DATA ADDRESS exception code.

- The Read Registers function code can be used to read data from multiple registers of the same or different data types. In this case, the starting register address must be of either a single-register data type or the first register in a multiple-register data type. The last register read must be either a single-register data type or the last register in a multiple-register data type. Attempting to start or end the read within a multiple-register data type will result in an exception response with the ILLEGAL DATA ADDRESS exception code.

- Some registers are designated as write-only (W versus R/W in the register map). Attempting to read a write-only register, the device will result in an exception response with the WRITE-ONLY REGISTER exception code.

The response to a read registers command is typically returned in less than 50 milliseconds.

8.6.3 Write Multiple Registers

This function code is used to write the contents of a contiguous block of registers.

Command			
Byte Offset	Field Description	Type	Value
0	Device Address	BYTE	1-247
1	Function Code	BYTE	16 (0x10)
2	Starting Register Address	USHORT	0-65535 (0xFFFF)
4	Number of Registers (N)	USHORT	1-123 (0x007B)
6	Byte Count	BYTE	2 x N
7	Register Data	2 x N BYTES	

Response			
Byte Offset	Field Description	Type	Value
0	Device Address	BYTE	1-247
1	Function Code	BYTE	16 (0x10)
2	Starting Register Address	USHORT	0-65535 (0xFFFF)
4	Number of Registers	USHORT	N

The starting register address is one less than the starting register number. The byte count must be two times the number of registers to be written.

- If the Write Multiple Registers function code is used to write data to a single register, the register must be a single-register data type such as a USHORT. An attempt to write a single register within a multiple-register data type will result in an exception response with the ILLEGAL DATA ADDRESS exception code.

- If the Write Multiple Registers function code is used to write a multiple-register data type, the start register address must be of the first register in the field and the number of registers must include all registers in the field. If one or both parameters are invalid, the device will return an exception response with the ILLEGAL DATA ADDRESS exception code.

- The Write Multiple Registers function code can be used to write data to multiple registers of the same or different data types. In this case, the starting register address must be of either a single-register data type or the first register in a multiple-register data type. The last register written must be either a single-register data type or the last register in a multiple-register data type. Attempting to start or end the write within a multiple-register data type will result in an exception response with the ILLEGAL DATA ADDRESS exception code.

- Some registers are designated as read-only (R versus R/W in the register map). Attempting to write data to a read-only register will result in an exception response with the READ-ONLY REGISTER exception code.

- If an attempt is made to write an out-of-range value to a register, an exception response with the ILLEGAL WRITE VALUE exception code will be returned.
- If the function returns an exception response with an exception code of ILLEGAL DATA ADDRESS or READ-ONLY REGISTER, no data was written to any of the registers.
- If the function returns an exception response with an exception code of ILLEGAL WRITE VALUE or DEVICE FAILURE, data was written to registers up to but not including the register that caused the exception. No data was written to registers after the register that caused the exception. There is no provision in the exception response to isolate the problem register.

The response to a write multiple registers command is typically returned in less than 100 milliseconds.

8.6.4 Write Single Register

This function code is used to write the contents of a single register. Only single-register data types can be written with this function. Writing to a multiple-register data type requires the Write Multiple Registers function code.

Command			
Byte Offset	Field Description	Type	Value
0	Device Address	BYTE	1-247
1	Function Code	BYTE	6 (0x06)
2	Register Address	USHORT	0-65535 (0xFFFF)
4	Register Data	USHORT	0-65535 (0xFFFF)

Response			
Byte Offset	Field Description	Type	Value
0	Device Address	BYTE	1-247
1	Function Code	BYTE	6 (0x06)
2	Register Address	USHORT	0-65535 (0xFFFF)
4	Register Data	USHORT	0-65535 (0xFFFF)

The register address is one less than the register number.

- An attempt to write a single register within a multiple-register data type will result in an exception response with the ILLEGAL DATA ADDRESS exception code.
- Some registers are designated as read-only (R versus R/W in the register map). Attempting to write data to a read-only register will result in an exception response with the READ-ONLY REGISTER exception code.
- If an attempt is made to write an out-of-range value to a register, an exception response with the ILLEGAL WRITE VALUE exception code will be returned.

The response to a write single register command is typically returned in less than 100 milliseconds.

8.6.5 Exception Response

When the device encounters an error condition in a command from the Master, it will reply to the command with the standard MODBUS exception response.

Exception Response			
Byte Offset	Field Description	Type	Value
0	Device Address	BYTE	1-247
1	Function Code + 128 (0x80)	BYTE	128-255 (0x80-0xFF)
2	Exception Code	BYTE	0-255 (0xFF)

8.6.5.1 Standard Exception Codes

The following exception codes are defined by the MODBUS protocol.

Exception Code	Name	Description
1 (0x01)	ILLEGAL FUNCTION	The function code received in the command is not valid for the device.
2 (0X02)	ILLEGAL DATA ADDRESS	The register address or the register range received in the command is not valid.
3 (0x03)	ILLEGAL DATA VALUE	A value contained in the command is not valid, such as a mismatch between the number of registers and the byte count. This exception indicates an error in the structure of a command.
4 (0x04)	DEVICE FAILURE	An error occurred in the device while attempting to perform the command.
10 (0x0A)	GATEWAY PATH UNAVAILABLE	An attempt was made to use pass-through communication while data logging is enabled.

8.6.5.2 Custom Exception Codes

The following exception codes are device-specific extensions to the standard codes to help speed command/response troubleshooting.

Exception Code	Name	Description
128 (0x80)	READ-ONLY REGISTER	The command attempted to write data to a read-only register.
129 (0x81)	WRITE-ONLY REGISTER	The command attempted to read data from a write-only register.
130 (0x82)	ILLEGAL WRITE VALUE	The command attempted to write an illegal or out of bounds value.
131 (0x83)	CORRUPT DATA RECORD	The requested data record is corrupted.
132 (0x84)	DOWNLOAD END	End of fast data log download.
133 (0x85)	SECURITY MODE	The requested function is not available in security mode.